THE NICKEL BULLETIN

A SUMMARY OF CURRENT INFORMATION ON NICKEL

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PHYSICAL AND MECHANICAL PROPERTIES OF PURE NICKEL

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THE MOND NICKEL COMPANY LTD • SUNDERLAND HOUSE, CURZON STREET, LONDON, W.1
Telephone:- Grosvenor 4131

PHYSICAL AND MECHANICAL PROPERTIES OF PURE NICKEL

High Purity Nickel

Composition, *per cent.*		99·94+

Physical Properties

Atomic number		28
Atomic weight		58·69
Atomic weights of isotopes		58, 60, 61, 62
Crystal form		Face - centred cubic (close-packed hexagonal form has been reported for some films)
Lattice constant		
	24·8°C.	3·5168Å
For close - packed hexagonal		a=2·49Å
		c=4·08Å
Specific gravity		
Computed	at 20°C.	8·908
Worked and annealed;	at 25°C.	8·901-8·903
Cast	at 23°C.	8·907
Emissivity (monochromatic 0·65μ) for brightness match optical pyrometry		0·355
Emissivity (total)	at 1000°C.	0·19
Reflectivity		
(yellow-green)	at ·55μ	0·64
(ultra-violet)	at ·30μ	0·413
(infra-red)	at 2μ	0·835
	at 3μ	0·870

Electrical Properties

Thermal E.M.F. *Versus* Pt *volts*		
	at 0°-100°C.	$1·485 \times 10^{-3}$
Electrical Resistance, *microhms/cm./sq. cm.*	0°C.	6·141
	20°C.	6·844

Electrical Resistance at other Temperatures (R_t = Resistivity at t°C., R_o = Resistivity at 0°C.)

t°C.	R_t *microhms/cm./sq.cm.*	$\frac{R_t}{R_o}$
−200	0·49	0·08
−100	2·82	0·46
0	6·14	1·0
+100	10·3	1·68
200	15·8	2·57
300	23·0	3·75
400	30·6	4·99
500	34·2	5·57
600	37·2	6·06
700	39·9	6·50
800	42·8	6·97
900	45·5	7·41
1000	48·3	7·86

Magnetic Properties

Curie temperature °*C.*	353 (approx.)
Magnetic saturation value, gauss	6500
Maximum Permeability H=1 oersted	2000-3000
Initial Permeability	200 (approx.)
Magnetostriction at saturation	$-32 \times 10^{-6} \Delta 1/1$

Thermal Properties

Freezing Point, °*C.*		1455
Latent heat of fusion, *cal./gram*		73
Boiling Point, °*C.*		3380 (approx.)
Vapour Pressure, *mm. Hg.*		
	at 1000°C.	$1·2 \times 10^{-6}$
	at 1455°C.	$9·4 \times 10^{-3}$
	at 2000°C.	2·3
Specific Heat		
	at 100°C.	0·1123
	at 200°C.	0·1225
	at 300°C.	0·1367
	at 400°C.	0·1267
	at 500°C.	0·1265
	at 600°C.	0·1326
Thermal Conductivity, *c.g.s. units*		
	at 100°C.	0·198
	at 200°C.	0·175
	at 300°C.	0·152
	at 400°C.	0·142
	at 500°C.	0·148
Coefficient of Thermal Expansion, *millionths per deg. C.*		
	at 20°C.	12·5
	at 100°C.	13·5
	at 200°C.	14·5
	at 300°C.	16·3
	at 400°C.	16·3
Average Coefficient of Thermal Expansion, *millionths per deg. C.*		
	−180 to 0°C.	10·22
	0 to 100°C.	13·3
	0 to 300°C.	14·63
	0 to 500°C.	15·45
	25 to 100°C.	13·3
	25 to 300°C.	14·4
	25 to 600°C.	15·5
	25 to 900°C.	16·3

Commercial Nickel

Typical Composition

	Wrought, per cent.	Cast, per cent.
Nickel*	99·51	Bal.
Copper	0·07	0·3 max.
Iron	0·14	1·0 max.
Manganese	0·13	0·5-1·5
Silicon	0·03	1·0-2·0
Carbon	0·09	0·3 max.
Sulphur	0·005 max.	0·05 max.

*Includes a small amount of cobalt.

Physical Properties

Specific Gravity	8·88
Weight, *lb./cu. in.*	0·321

Thermal Properties

Melting Range °C.		1435-1445
Specific Heat	27°-100°C.	0·110
Coefficient of Thermal Expansion, *millionths per deg. C.*		
	25°-100°C.	13·3
	300°-600°C.	16·5
Thermal Conductivity, *c.g.s. units*		0·145

Electrical Properties

Electrical Resistance		
20°C.	*microhms/cm./sq. cm.*	9·0
20°C.	*ohms/sq. mil. ft.*	42·5
20°C.	*ohms/cir. mil. ft.*	54
Temperature Coefficient of Electrical Resistance		
0°-100°C.		0·004-0·006

Magnetic Properties

Saturation Induction	6000 gauss (approx.)
Magnetic Permeability	
H = 20 oersteds	1000 (approx.)
Initial Permeability	200 (approx.)
Magnetic Transformation Point, °C.	360

Speed of Sound

Longitudinal Bar, *cm. per sec.*	$4{\cdot}7 \times 10^5$

Modulus of Elasticity

millions of lb./sq. in.	
In Tension	28-30
In Torsion	11

Mechanical Properties at Room Temperatures

Table I

Typical Tensile Data

	Rounds	Squares	Rectangles, Hexagons	Plate	Sheet and Strip		Wire		Tubing		Castings
	Hot-rolled	Cold-rolled or drawn	Annealed	Hot-rolled	Cold-rolled as rolled	Cold-rolled Annealed	Cold-drawn Regular Temper	Cold-drawn Annealed	Cold-drawn	Annealed	As Cast
0·2% proof stress, *tons/sq. in.*	10	33	7	11	35	8	48	8	28	8	9
Maximum stress, *ton/sq. in.*	34	43	29	36	45	30	55	33	40	30	26
Elongation on $4\sqrt{\text{area}}$, *per cent.*	45	25	50	45	15	45	10	45	28	45	20
Hardness, D.P.N.	105	185	95	125	190	110	—	—	180	110	110

Table II

Comparison of Strength in Shear and Tension

	Temper		
	Annealed	Half hard	Full hard
Shear Strength, *t.s.i.*	23	26	33
Maximum Stress, *t.s.i.*	30	35	54
Hardness, D.P.N.	105	190	250

Table III

Compression, Tension and Hardness

Typical Data

	Hot-Rolled	Cold-Drawn 24%	Annealed
Tensile Data			
Proportional Limit, *t.s.i.*	8	23	8
0·2% Proof Stress, *t.s.i.*	11	28	12
Maximum Stress, *t.s.i.*	32	39	33
Compression Data			
Proportional Limit, *t.s.i.*	8	18	7
0·2% Proof Stress, *t.s.i.*	10	26	12
Hardness, D.P.N.	120	190	120

Mechanical Properties at Room Temperatures *(continued)*

Table IV

Fatigue and Corrosion Fatigue Limits

No. of Cycles to Failure	Stress to Cause Failure, *tons/sq. in.*					
	Cold-Drawn Rod Tested in			Annealed Rod Tested in		
	Air	Fresh Water	Sea Water	Air	Fresh Water	Sea Water
10^4	49	49	—	—	—	—
10^5	37	36	—	23	23	23
10^6	28	25	24	18	17	16
10^7	23	15	13	15	12	11
10^8	22	12	10	15	10	9
10^9	22	11	9	15	10	9

The stress given is the stress in one direction only. The method of testing causes stress to vary from these values in tension to the same values in compression, and return, during each cycle of operation. These figures were determined by McAdam (*Proc. A.S.T.M.*, vol. 27, 1927, pp. 102-27) using rotating cantilever test pieces. The cold-drawn specimens had an average tensile strength of 59 tons per sq. in. and the annealed specimens 35 tons per sq. in.

Mechanical Properties at High Temperatures

Table V

Short Time Tensile Properties

Temperature °C.	0·2% Proof Stress *tons/sq. in.*	Maximum Stress *tons/sq. in.*	Elong. on $4\sqrt{\text{area}}$ *per cent.*
Room	11	33	49
90	9	34	52
150	9	34	46
200	10	35	49
260	11	34	48
320	10	37	50
370	10	36	50
430	9	34	52
480	9	29	51
540	8	20	55
600	7	16	55
650	7	15	57
700	6	14	59
760	5	12	61
820	—	11	65
870	—	7	76
930	—	5	84
980	—	3·5	91

All specimens were of hot-rolled material and held ½ hour at temperature before testing. Rate of pulling: 0·0016 in. per min. to yield; then 0·0026 in. per min. till fracture.

Mechanical Properties at Low Temperatures

Table VI

Charpy Impact Values

Temperature °C.	Hot-Rolled *ft.-lb.*	Cold-Drawn *ft.-lb.*	Annealed *ft.-lb.*
Room	195	185	216
−80	236	205	235
−190	227	210	234

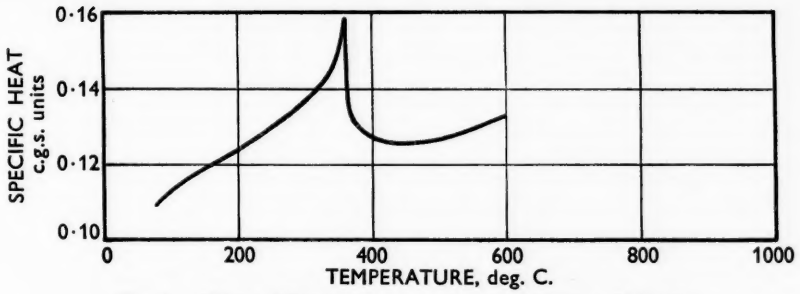

Fig. 1. Effect of Temperature on the Specific Heat of Nickel.

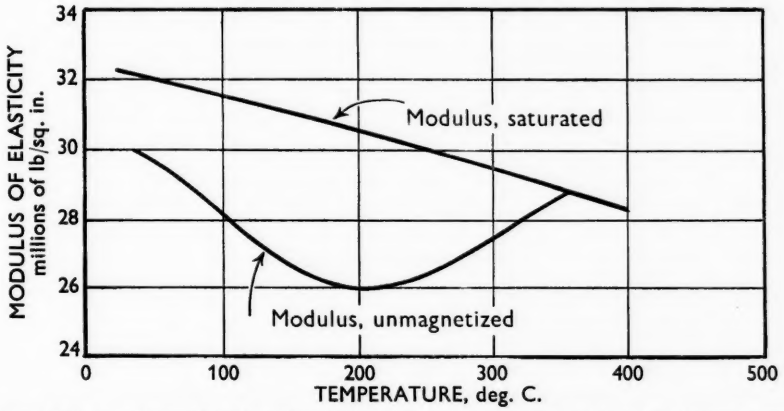

Fig. 2. The Modulus of Elasticity is affected not only by temperature but also by Magnetic conditions.

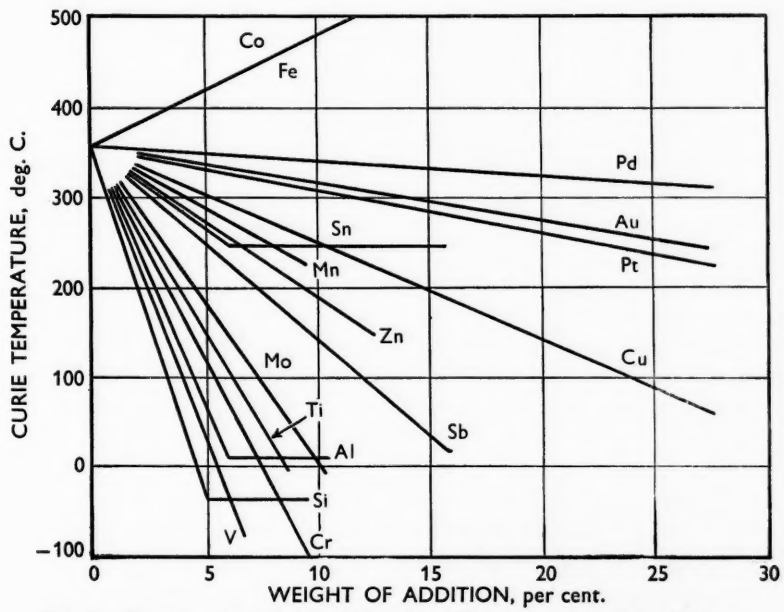

Fig. 3. How the Curie Point of Nickel is affected by single alloy additions.

Reference to the sources from which these data have been compiled will be supplied on request.

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Machinability Ratings of Nickel-containing Materials

'Machinability Research Program Reported.' *Iron Age*, 1950, vol. 166, Nov. 9, pp. 99-102.

This article is based on data published in a book recently issued by Curtiss-Wright Corporation, describing a systematic research on machinability carried out under sponsorship of the U.S. Air Force. Participating industrial organisations included Ford Motor Company, Metcut Research Associates, Massachusetts Institute of Technology, and Curtiss-Wright Corporation.

The full report comprises a basic analysis of machining conditions, covering tool design and selection, influence of microstructure, evaluation of productivity of machine tools, and a study of all the variables involved in machining of standard steels, high-temperature alloys and cast irons.

The extract in *Iron Age* gives an account of some of the methods and equipment used, and reproduces tables giving:—

(1) Mechanical and machining properties of gas-turbine alloys (S-816, Inconel 'X', Timken 16-25-6, A.I.S.I. steels 347, 4340, 410 and 8640).
(2) Compositions, mechanical properties and tool life of flake-graphite and nodular-graphite cast irons.
(3) Comparison of the mechanical properties of a typical cast steel and nodular cast iron.

NICKEL

Constitution and Structure of Nickel-containing Catalysts

J. LONGUET-ESCARD: 'Structure of the Hydroaluminates of Nickel.' *Jnl. de Chimie Physique*, 1950, vol. 47, Mar.-Apr., pp. 238-41.

The substance obtained by addition of sodium to a mixture of the nitrates or chlorides of nickel and aluminium, of high nickel-salt content, shows, after washing, drying and grinding of the precipitate, a Debye-Scherrer diagram which differs from that of the hydroxide of nickel (brucite) and aluminium hydroxide (hydrargillite), indicating the formation of a hydrated nickel aluminate. This observation was announced by the present author in 1948, and the paper now published gives further information on the characteristic structure of the compound, which has been found in catalysts used in the Fischer-Tropsch reaction.

Y. TRAMBOUZE: 'Chemical Transformations of Fischer Catalysts in the Course of Preparation.' *ibid.*, pp. 258-60.

The paper reports a study of the conditions of formation, and influence of various factors, on the composition of Fischer catalysts of the nickel hydroxide/kieselguhr/alumina type. The composition of the catalyst at various stages in its preparation was observed, with particular reference to the different states of combination of the nickel constituent. X-ray analysis of catalysts of this type confirmed the presence of nickel hydrosilicate and nickel hydroaluminate.

A. MICHEL *et al.*: 'Thermomagnetic Study of Fischer Nickel Catalysts.' *ibid.*, pp. 269-73.

A report of the application of thermomagnetic analysis to determination of the composition of complex Fischer catalysts containing nickel 41-100, thorium dioxide 0-·18, per cent., and some kieselguhr. A close relationship was found between catalytic activity and modulus of fineness, and there was also some parallel between catalytic behaviour and ferromagnetism. It is found that, under certain conditions, nickel may be transformed to a paramagnetic hexagonal carbide, with intermediate formation of a solid solution of carbon in a face-centred-cubic nickel lattice. Nickel in active catalysts is believed to have small amounts of carbon in its crystal lattice

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Y. TRAMBOUZE and M. PERRIN: 'Effect of Chemical Composition of Fischer Catalysts and their Components on their Activity in Synthesis.' *ibid.*, May-June, pp. 474-81.

The catalysts studied were prepared from an aqueous solution of nickel nitrate, manganese nitrate and aluminium nitrate, to which kieselguhr was added. The metallic ions were precipitated by addition of sodium carbonate solution; the washed precipitate was dried, and the catalysts were kept in a current of air to prevent their becoming brown and inactive.

Activity of catalysts so prepared was studied, as affected by alkalinity, preheating, and state of combination of the nickel present. The results showed that a specific rôle was played by hydroaluminates of nickel; chemical analysis of the hydroaluminates and result of X-ray diffraction studies of their structure are recorded. The influence of heating of the aluminate was also determined.

The results indicate that the method of preparation of the catalyst is an important factor in determining its composition and structure; the principal components are nickel hydroaluminate and nickel hydrosilicate. The activity of catalyst of the type described was tested in various organic reactions.

Nickel Catalysts: Effect of Temperature of Production

J. FRANCOIS: 'Influence of Temperature on Dimensions of Nickel Oxide Particles.' *Comptes Rendus*, 1950, vol. 230, pp. 1282-4.

Lessening of activity which has been observed in nickel-oxide catalyst prepared at temperatures above about 400°C. is accompanied by rapid increase in the size of the particles. It is suggested that the oxide, at these temperatures, undergoes a sintering, resulting in aggregation of the smaller particles with larger ones. Experiments on oxides obtained by calcination of the nitrate or the hydroxide confirmed the conclusions drawn.

The results reported agree with those of earlier investigators in showing that the black oxide of nickel is active, while the grey variety is inactive, as a catalyst.

Electrodeposition of Nickel Powder

See abstract on p. 8.

Electropolishing of Nickel

G. W. WENSCH: 'Electrolytic Polishing of Nickel.' *Metal Progress*, 1950, vol. 58, Nov., pp. 735-6.

This note describes a modified method developed on the basis of that proposed by Hothersall and Hammond (*Jnl. Electrodepositors' Tech. Soc.*, 1940, vol. 16, p. 83; *Nickel Bulletin*, 1941, vol. 14, No. 2, p. 19).

The details given of the modified procedure are shown below:—

Solution: 390 cc. concentrated sulphuric acid plus 290 cc. distilled water.

Cathode: Nickel.

Current Density: 39 amp./sq. dm.

Time: 4 to 6 min.

Temperature: 95°F. (35°C.) max.

The electropolished surface so produced is stated to have very high reflectivity, and no etching occurs when the solution is used at lower current densities.

Nickel polished by this method can be successfully electro-etched, using the following conditions:—

Solution: 53 cc. 85 per cent. orthophosphoric acid to 100 cc. distilled water.

Current Density: 1·55 amp./sq. dm.

Time: 1 to 4 min.

A photomicrograph accompanying the note demonstrates the clarity of delineation obtained.

Nickel-containing Materials in Cathodic Protection Systems

See abstract on p. 22.

ELECTRODEPOSITION AND OTHER COATING METHODS

Maintenance of the Standard of Nickel Plating

C. W. J. MORLEY: 'The Nickel Shortage. Maintaining Production Under Present Conditions.' *Metal Industry*, 1950, vol. 77, Nov. 24, pp. 218-19.

It is generally agreed, in all countries, that standards which have been reached in the plating industry, as a result of the educative work of many years, should not lightly be thrown aside. If, however, maintenance of quality is to be ensured in the face of drastically curtailed supplies of nickel, overhaul of practice, and the elimination of waste in all stages of the plating process are urgently called for.

This article is written with a view to giving practical assistance to this end. Suggestions are made with regard to the following points:—

Use of insulated jigs.
Avoidance of drag-out.
Operation of vats at optimum pH and temperature.
Adequate preparation prior to plating, in order that the plater may produce a clean job, requiring a minimum of finishing.
Use of bright nickel, in order to cut out finishing operations which remove plate.
Checking of anode bags and repair of faulty ones, and correct placing of bags in the solution.
Determination of optimum loading of the vat.
Periodic renewal of cleaner.
Use of scrap nickel as anodes, by means of anode economizers.
Minimizing of plating-out periods.
Control of electrical equipment.
Time-control in plating.

It is suggested that a further step which may usefully be explored as a means of saving nickel is the use of the periodic-reverse-current copper-plating process (extensively employed in the U.S.A.), by which mirror-bright and smooth undercoats are obtained, requiring a minimum final coating of nickel or nickel+chromium.

Addition Agents in Bright Nickel-Plating Solutions

'Bright Nickel Plating. Some Further Udylite Patents Reviewed.' *Electroplating*, 1950, vol. 3, Nov., pp. 567-9.

The article is a summary of three British patents recently granted to the Udylite Corporation (Nos. 638,307, 638,867 and 638,868). They relate to anti-pitting and other addition agents, suitable for use in organic- and/or cobalt-type bright-nickel-plating baths.

It is claimed that the lauric acid mono-ester of diethylene glycol sulpho-acetate (0·1-0·5 g./L.) will prevent pitting in bright plating baths used for the deposition of nickel, cobalt, iron, zinc, cadmium or their alloys, or of copper or antimony alone. Brilliance in nickel deposits on polished surfaces is promoted by an alpha or beta unsaturated aliphatic sulphonic acid, sulphonamide or sulphonimide, while the rate

of brightening on dull surfaces is promoted by a soluble *N*-alkyl pyrazolyl quinolinium quaternary salt in which the alkyl group contains 1-8 carbon atoms. An alternative to the last-mentioned addition is a soluble alkyl pyridinium, quinolinium or iso-quinolinium quaternary salt. A table of recommended compounds, in optimum concentrations, is given in the abstract.

Electrodeposition of Nickel Powder

G. WRANGLEN: 'Electrodeposition of Metal Powders.' *Jnl. Electrochemical Soc.*, 1950, vol. 97, Nov., pp. 353-60.

Metal powders may be produced electrolytically by two methods: (1) direct deposition on the cathode as a powdery or spongy material which will give powder either directly or after light rubbing, *or* (2) production of a brittle electrodeposit which may be ground to a powder. Method (1) is most important for metals characterized by low overvoltage; method (2) applies chiefly to the iron-group metals, which have high metal overvoltage and can easily be obtained in a brittle condition, owing to co-deposition of a finely divided basic material (hydroxide). Metals of low overvoltage, e.g., copper, can be obtained in brittle form by means of addition agents.

The papers deal only with production of powders by the direct method (1), discussing the principles underlying the process, and reviewing data on electrodeposition of individual metal powders by the electrolytic method.

The following factors are of importance for formation of powdery and spongy metal deposits on the cathode:

(1) Low metal overvoltage.

(2) Depletion of the metal content of the cathode film.

(3) Formation of basic material in the cathode film.

The influence of these three factors is reviewed.

The experimental section of the paper reports work on electrodeposition of the following types of metal powder: copper, iron, nickel, zinc, cadmium. Previous literature is correlated with the author's results, which include data on production conditions, and the influence of variables in operation on the structure of the powders produced and their characteristics.

With regard to nickel, the following observations are made:—

'It is more difficult to obtain a powdery deposit of nickel than of iron. This result is partially explained by the higher metal overvoltage of nickel. If a nickel salt solution is electrolyzed under conditions usually favourable to powder formation, often the only result is a deposit of basic material on the cathode. If ammonium salts are added, nickel, free from visible basic inclusions, is obtained with good current efficiency, even at low temperatures, in neutral solutions containing suspended hydroxide.

'However, an entirely powdery deposit, similar to those of iron, was obtained readily in ammoniacal nickel solutions. Thus, under the conditions: 10 g./L. of Ni as $NiCl_2$, 250 mL./L. of concentrated NH_4OH (giving a pH of about 11), 15 amp./sq. dm., 50°C., and a stationary electrolyte, a fine powder was obtained with a current efficiency of 90 per cent. It could be removed from the cathode by spraying with water. Although the solution mentioned was slightly turbid, it is likely the depletion factor was more important than the presence of basic material in the formation of the powder.'

The paper does *not* include any illustrations of nickel powder.

See also closely similar paper by the same author entitled 'On the Principles of Electrodeposition of Metal Powders.' *Trans. Roy. Inst. Technology, Stockholm*, 1950, No. 37; 30 pp.

Nickel in Coinage Alloys

See abstract on p. 9.

Electrodeposition of Copper on Stainless Steel

M. B. DIGGIN: 'Plating of Copper on Stainless Steel Pans.' *Plating*, 1950, vol. 37, Nov., p. 1163.

In reply to an enquiry for a method of plating stainless steel pans, the following recommendations are made:—

'Numerous activation methods are described in the literature. Among cathodic treatments used successfully is the treatment in 5-50 per cent. sulphuric acid at room temperature. In U.S. Patent 2,363,973, Nov. 28, 1944, to J. M. Kennedy et al., assignors to Revere Copper and Brass, Inc., the surface, after having been cathodically treated in sulphuric acid, is first given a strike coating in a dilute copper sulphate-sulphuric acid bath and then copper plated in a more concentrated copper sulphate-sulphuric acid bath. In a modification of the method, the article is made the cathode, the anode, and again the cathode, in dilute sulphuric acid, best results having been obtained in a 30 per cent. (by weight) sulphuric acid solution to which may be added 10 per cent. (by weight) of anhydrous sodium sulphate.

'Another method makes use of simultaneous activation and plating in a nickel chloride (32 oz./gal.), hydrochloric acid (11-16 oz./gal.) strike at room temperature for ½-3 minutes at 75 amp./sq. ft. The anodes are electrolytic nickel. After the thin nickel film has been deposited, the articles can be transferred to any common plating solution for build-up of the desired deposit.'

NON-FERROUS ALLOYS

Metals for the Motor Industry: B.S. Handbook

See abstract on p. 14.

Effect of Rate of Freezing on Segregation in Nickel-Copper Alloys

W. T. OLSEN and R. HULTGREN: 'Effect of Rate of Freezing on Degree of Segregation in Alloys.' *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1950, vol. 188, p. 1323; T.N. 48E; *Jnl. of Metals*, Nov., 1950.

The authors present a summary of results of experiments on copper-nickel and copper-gold alloys, indicating that segregation can be completely suppressed by very rapid rates of cooling. For the alloys studied (55-45 copper-nickel and 83·5/16·5 gold-copper) the rates required are, however, too high to be attained in commercial practice. A tabular summary includes data for the copper-nickel alloy cooled at the following rates (°C. per sec.): 0·0055; 5,700; 13,300; 97,000.

In the copper-nickel system the greatest segregation is found at the slowest cooling rates, where the lowest percentage of copper theoretically possible is found. In the gold-copper system, however, the degree of segregation is decidedly less at the slowest rates of cooling, being greatest at 11,100°C. per sec.

At rates of cooling occurring in sand- and die-casting the degree of segregation is large, and depends little on the rate of cooling.

Nickel in Coinage Alloys: Electroformed Nickel in Printing-Plate Production

'Seventy-Ninth Annual Report of the Deputy Master and Comptroller of the Royal Mint 1948.' Published by H.M.S.O., 1950; 80 pp. Price 2/-.

The Report gives the usual statistics of coins struck and issued (including cupro-nickel and nickel-brass denominations), for Great Britain, Dominion, Colonial, and foreign countries, and of medals for the production of which the Mint is responsible.

In view of the very small holdings of the Bank of England in Imperial silver and cupro-nickel coins at the beginning of 1948, special arrangements were made at the Mint to produce the maximum possible quantity of Imperial cupro-nickel coins. Results achieved are referred to in Appendix I of the present Report, including tabular comparison of metal melted and bars produced in 1947 and 1948. Appendix II gives an account of the assays made during 1948, and also contains a description of a photo-etching process used for reproduction, on a printing block, of a design (for notes) having a wide variety of fine lines. A specially prepared brass sheet is used as a base. Reference is also made to the use of electroformed matrices in the production of duplicate printing plates for stamps, and of a process modified from it, for production of seals. The following steps are the essential features of the process:

The stamp-plate master is produced by electrodeposition of copper on an assembly of lead impressions, each of which is struck from an engraved steel die in a steel collar. The struck leads are assembled in a gun-metal chase to size and square, and copper is deposited on them from an acid sulphate bath. When the copper layer is sufficiently thick it is released from the assembly lead impressions by heat persuasion, and reinforced by casting upon it a backing of lead-tin-antimony alloy. This backing is subsequently machined, and the plate is flattened and finished.

The copper master stamp plate, prepared in this way, is treated successively by cathodic cleaning, stopping off at back and edges, cleaning, silvering, iodizing, washing and drying. It is then re-wetted and a fine film of copper is deposited on the surface of the plate, from a bath of low acid content, using low current density. Finally, the treated master is transferred to a normal acid copper solution and treated until the requisite thickness is deposited. Separation is effected by wedging a knife edge between the plates.

The duplicated stamp, or working plate, is produced by repeating the above process with the matrix in place of the master, so producing a duplicate of the master, without harm to the latter. The duplicated plate is finished in the same way as the master, and is finally chromium plated.

In cases where a nickel plate backed with copper is required, separation from the matrix is effected by treating the surface with a solution of potassium bichromate. Silvering is not essential, but is an aid to separation. The nickel deposit should be 0·005-0·010 in. thick. Good adhesion of the copper to the nickel is essential; this is ensured by a rinse in dilute sulphuric acid before copper plating.

A modification of the above processes (which have been found to result in remarkably true reproduction) is now used for production of nickel-copper seals, from any suitable relief or counterpart. Electroformed nickel seals and copper counterparts are found to match up perfectly for the embossing of paper and wafers.

A further item of interest in connexion with nickel-containing coinage is the report (Appendix VI) of the results of the Trial of the Pyx, in which verdicts delivered on cupro-nickel coinage, as well as on silver denominations, are included.

Appendix VII contains the Proclamation determining New Designs for the Silver, Cupro-Nickel, Mixed Metal and Bronze Coins.

Later Appendices contain the Reports of the Dominion and Colonial Mints.

Nickel-containing Materials in Cathodic Protection Systems

See abstract on p. 22.

Nickel-containing Materials in Protection of Marine Structures

See abstract on p. 23.

Corrosion-Resistance of Iron-containing Cupro-Nickel

See abstract on p. 22.

NICKEL-IRON ALLOYS

Constitution of Nickel-Iron, Nickel-Iron-Aluminium, and Nickel-Chromium-Iron Alloys

Discussions on the papers detailed below are published in *Jnl. Iron and Steel Inst.*, 1950, vol. 166, Nov., pp. 200-12.

The references given in brackets after the individual papers are to the publication of the originals, and the *Nickel Bulletin* abstracts.

E. A. OWEN and Y. H. LIU: 'Further X-ray Study of the Equilibrium Diagram of the Iron-Nickel System' (*Jnl. Iron and Steel Inst.*, 1949, vol. 163, pp. 132-7; *Nickel Bulletin*, 1949, vol. 22, No. 12, p. 195).

F. W. JONES and W. I. PUMPHREY: 'Free-Energy and Metastable States in the Iron-Nickel and Iron-Manganese Systems' (*Jnl. Iron and Steel Inst.*, 1949, vol. 163, pp. 121-31; *Nickel Bulletin*, 1949, vol. 22, No. 12, p. 196).

A. J. BRADLEY: 'Microscopical Studies on the Iron-Nickel-Aluminium System. Part I. $\alpha+\beta$ Alloys and Isothermal Sections of the Phase-Equilibrium Diagram' (*Jnl. Iron and Steel Inst.*, 1949, vol. 163, pp. 19-30; *Nickel Bulletin*, 1949, vol. 22, No. 10, p. 158).

W. P. REES, B. D. BURNS and A. J. COOK: 'Constitution of Iron-Nickel-Chromium Alloys at 650° to 800°C.' (*Jnl. Iron and Steel Inst.*, 1949, vol. 162, pp. 325-36; *Nickel Bulletin*, 1949, vol. 22, Nos. 8-9, p. 141).

Ferromagnetic Spinels containing Nickel

R. L. HARVEY, I. J. HEGYI and H. W. LEVERENZ: 'Ferromagnetic Spinels for Radio Frequencies.' *R.C.A. Rev.*, 1950, vol. 11, Sept., pp. 321-63.

The paper is introduced by the following note on terminology for this type of material:—

'The coined work 'ferrospinel' is used to denote a ferromagnetic spinel, which is a species of non-metallic cubic crystalline material containing iron in combined form. The term ferrospinel seems doubly appropriate because the materials utilize chiefly the spin property of unpaired electrons. Ferrospinels are sometimes called 'ferrites', a term which is inappropriate because the word ferrite has long been used to denote a form of metallic (α) iron containing a fraction of a per cent. of carbon.'

The paper describes the range of ferrospinels, a series of unique crystalline materials formed at high temperatures by solid-phase reaction of iron oxide and one or more of certain other metal oxides. These substances are ceramic-like materials characterized by high magnetic permeability (in some cases over 1200), high electrical resistivity (up to 108 ohm/cm.) and low losses at radio frequencies. Wide ranges in properties may be obtained by variation in the nature and proportions of the constituents, and by changes in methods of synthesis.

This paper contains, as a background, an outline of the elementary theory of magnetism, followed by a detailed description of the structures, modes of synthesis, properties, and uses of ferrospinels which have recently become of practical importance.

Since nickel-zinc ferrospinels have been found to be of particular value in many applications, a large part of the paper is devoted to a consideration of this type of material. Operations in synthesis are exemplified by description of the steps involved in preparation of an equimolar solid solution of nickel ferrospinel and zinc ferrospinel, in a form suitable for measurement purposes. The material is prepared from chemically pure oxides. Electrical and magnetic characteristics, and the general behaviour of the ferrospinels are also presented, in the form of data on the nickel-zinc-containing type.

The following notes are added with regard to established and potential uses of the new materials:

'Ferrospinels are being used increasingly in electronic equipment operating in the frequency range of 10 to 5,000 kilocycles. At power and low audio frequencies they are not competitive with laminated ferromagnetic materials, and at very high frequencies the losses in the ferrospinels are excessive when high permeability is required. It is possible, however, to produce a ferrospinel, with low permeability, useful at frequencies in order of 100 megacycles. The application of ferrospinels as core bodies in the deflection yoke, horizontal deflection transformer, and high-voltage transformer for television receivers is now finding wide acceptance. The ferrospinels are especially suited to television video frequencies, as their use in these components results in improved performance, at lower cost and with smaller space.'

'In the standard broadcast receiver, the ferrospinels are expected to be used in the radio frequency circuits as 'trimmers', and as permeability tuning cores. With a properly designed coil, it is possible to tune a circuit by the movement of a ferrospinel rod, from 500 to 3000 kilocycles, or to cover the standard broadcast band (540-1730 kilocycles), with only three-eighths of an inch movement of the ferrospinel rod. Uses of ferrospinels in receiver design are illustrated. Some of the ferrospinels are also useful for magnetostriction applications, and have been employed as 'driver' and 'take-off' elements for resonant metal filters.'

The paper is supported by a useful *bibliography* of 36 references.

CAST IRON

Notch Sensitivity of Nickel-Alloy Cast Irons

T. E. EAGAN: 'Notch Sensitivity of Various Cast Materials.' *Amer. Foundryman*, 1950, vol. 18, Nov., pp. 22-4; corrigendum, Dec., p. 63.

The author refers, in introduction, to the excellent review of the literature and summary of the current position of knowledge contained in 'Prevention of

Fatigue of Metals', published for Battelle Memorial Institute, by John Wiley and Sons, Inc., in 1941. The present paper deals with work done since that date, with particular reference to tests made by Cooper Bessemer Corporation.

Detailed information is given on test results obtained on the following types of cast material:—

(1) *Forged Steel* to A.I.S.I. specification 1040 [section from forged crankshaft, heat-treated by quenching from 1550°F. (842°C.) and tempering at 1100°F. (593°C.)].

(2) *Cast Steel* to A.S.T.M. specification A-27, grade 65-30, calling for tensile strength of 65,000 p.s.i. (29·0 tons per sq. in.) and yield strength of 30,000 p.s.i. (13·5 tons per sq. in.). In this case treatment was 1650°F. (898°C.) for 5 hours; air cooling; 1250°F. (675°C.) for 5 hours; air cooling.,

(3) *Acicular Grey Cast Iron*, for which the specification was 60,000 p.s.i. (26·8 tons per sq. in.) minimum tensile, with a matrix structure at least 85 per cent. acicular. The iron is a type used for crankshafts.

(4) *Ductile or Nodular Cast Iron.* A magnesium-treated cast iron, tested in the annealed condition produced by heating for 2 hours at 1650°F. (898°C.), furnace cooling to 1250°F. (675°C.) and holding at that temperature for 10 hours, followed by furnace cooling.

(5) *Class* 50 *Grey Cast Iron.* An alloyed iron in which a minimum tensile strength of 50,000 p.s.i. (22·3 tons per sq. in.) is called for a 2-in. bar. No heat-treatment had been given.

Specimens used were 1-in. in diameter, and were tested in reverse bending, in a R.R. Moore-type fatigue-testing machine. Most of the testing was done with relatively sharp notches, but supplementary tests were made with a notch having a 0·050-in. radius, chosen as particularly capable of giving information useful in crankshaft design.

Results are summarized in table and figure. In the case of the notch-sensitivity value two methods of reporting were adopted: (1) showing percentage reduction of endurance limit due to the notch, (2) giving the stress-concentration factor:

$$K = \frac{\text{Endurance Limit of Unnotched Specimen}}{\text{Endurance Limit of Notched Specimen}}$$

The following comments are made on the results thus reported:—

'In the case of the forged steel having a tensile strength of 80,100 p.s.i. (35·75 tons per sq. in.), the unnotched endurance limit was 35,000 p.s.i. (15·6 tons per sq. in.) which gives a tensile/endurance-limit ratio of 0·44. Comparison of this ratio to values reported throughout the literature shows that within reason it is in agreement. The usual figure is between 0·40 and 0·50.

'The 0·050-in. radius notch gives an endurance limit of 17,800 p.s.i. (7·9 tons per sq. in.), which gives a concentration factor K of 1·96, in relative agreement with published data.

'Grouping the cast steel, acicular iron, and ductile iron, it is interesting to note that all three of these materials have about the same tensile strength, namely, 71,000 to 74,000 p.s.i. (31·7 to 33·0 tons per sq. in.).

'They also have the same unnotched endurance limit, 24,000 to 26,000 p.s.i. (10·7 to 11·6 tons per sq. in.), which gives a tensile/endurance-limit ratio of 0·33 to 0·35. These same three materials have about the same notched endurance limit, 17,000 to 19,000 p.s.i. (7·6 to 8·5 tons per sq. in.). The stress concentration factor K, however, is 1·53 for the acicular iron, which is considerably higher than for cast steel 1·26, and nodular iron 1·30.

'The ratio of tensile to unnotched endurance limit obtained for cast steel is considerably lower than that obtained by other investigators.' (Reasons for this discrepancy are discussed, but no positive explanation can be advanced.)

'Results obtained in the class 50 grey iron are in substantial agreement with published data, with the exception that the tensile strength limit, 0·34, is considerably below the usual figure quoted. In comparing the last four materials, it is noted that, due to notch sensitivity, the notched endurance limit is between 13,000 and 19,000 p.s.i. (5·8 and 8·5 tons per sq. in.) Under normal conditions a spread of 6000 p.s.i. would be rather insignificant. Attention is directed to this fact in order to emphasize that in many applications any one of these materials could be used interchangeably, provided that other considerations in design and foundry practice can be justified.'

Base Irons for Magnesium Treatment

E. M. STEIN: 'Nodular Iron Experiments.' *Foundry*, 1950, vol. 78, Nov., pp. 96-9, 214, 216-18, 220.

The article reports experiments in the Gunite Foundries Corporation, made to determine to what extent it would be necessary to modify the composition of their normal base iron, in order to obtain satisfactory response to magnesium treatment for production of nodular graphite. The investigation covered both cupola and electric-furnace irons. Regular-production cupola irons in this foundry are of the following types:—

	Type A %	Type B %
Total Carbon ..	3·30	3·55
Silicon	1·80	1·60
Manganese	0·65	0·70
Phosphorus	0·14	0·14
Sulphur	0·14	0·14
Copper	0·20	0·20
Nickel	0·10	0·10
Chromium	0·10	0·10
Molybdenum	0·10	0·10

Cupola Irons

The following magnesium alloys were used: nickel-magnesium 80-20 and 50-50; copper-magnesium 80-20 and 70-30; silicon-magnesium 34-7 and 43-9 (balance mostly iron).

Electric-Furnace Irons

One heat only was made. The main treatment was with nickel-magnesium alloy (which had proved most satisfactory in the cupola-iron experiments), but one test was made with copper-magnesium (which had failed to produce nodular graphite in the cupola tests).

Data on structures and properties obtained, magnesium recovery, and residual magnesium content, detailed in the paper, are summarized as follows:—

The use of cupola-base iron resulted in a predominantly pearlitic matrix as cast; the electric furnace nodular iron was mainly ferritic as cast.

For the as-cast pearlitic irons, tensile strengths of 80,000-100,000 p.s.i. (approx. 35·5-44·5 tons per sq. in.), with 1-3 per cent. elongation, were consistently obtained. It is considered that after more experience in production it should be possible, with a controlled cooling rate, to obtain 80,000-100,000 p.s.i. tensile and 5-10 per cent. elongation in the heat-treated condition.

In the electric-furnace iron tests, using nickel-magnesium alloy, 78,000-83,000 p.s.i. (34·5-37 tons per sq. in.), and 13-18 per cent. elongation were obtained. After annealing, or holding at 1350°F. (734°C.) for two hours, the corresponding figures were 68,600-77,700 p.s.i. (30·6-34·7 tons per sq. in.), and 16-22 per cent. elongation.

Based on the experience obtained in production of these irons, the following comments and recommendations are made:—

No definite conclusions were reached with regard to the difference in properties resulting from the variation in total carbon content (3·55 and 3·30 per cent., respectively).

Of the alloys mentioned above, the 80-20 nickel-magnesium type gave the most consistent results. In the cupola irons, the copper-magnesium addition failed to give a nodular structure, but in the electric-furnace iron complete nodularization was obtained with a similar addition. The silicon-magnesium-iron alloys gave inconsistent results.

Shrinkage was somewhat less in the higher-carbon (3·55 per cent.) series of the cupola irons than in the 3·30 total-carbon group, but with good risering methods sound castings were obtained with the 3·30 total-carbon grade also.

Few of the irons of either series showed pinholing, but in some cases where the metal was too cold at the time of inoculation, or where too much inoculant was used, some pinholing was encountered. Metal temperature at time of inoculation, and amount of inoculant, are believed to be major factors in control of this defect.

Machinability of the cupola magnesium-treated irons was found to be 'very definitely superior' to that of grey irons of similar hardness.

Fractures of the electric-furnace nickel-magnesium-treated iron varied from partially dark grey to almost completely dark grey, and it was observed that the greater the elongation the larger was the proportion of dark area. All other nodular bars showed 'steely' fractures.

In connexion with development of new applications for nodular cast irons, the writer emphasizes the importance of ensuring that design is adapted to the properties of the new materials.

Nodular Cast Iron: Influence of Heat-Treatment

R. Y. SCAPPLE: 'Nodular Cast Iron; Heat Treatment and Physical Properties.' *Iron and Steel*, 1950, vol. 23, Sept.-Oct., pp. 379-81.

The paper contains results of experimental work done in the metallurgy laboratories of Stanford University, on commercial samples of nodular-(spheroidal-) graphite cast iron received from two U.S. manufacturers. It is concerned essentially with the response of the irons to heat-treatment, and the effect of such treatment on mechanical properties. The compositions of the two cast irons used are shown below:—

	No. 1 Iron %	No. 2 Iron %
T.C. ..	3·48	3·90
Si	1·68	2·50
S	0·011	0·030
P	0·05	0·030
Mn ..	0·58	0·10
Ni ..	1·25	0·00
Cu.. ..	0·00	0·97
Mg ..	unknown	0·051

Prior to study of the modification of mechanical properties resulting from heat treatment, the following aspects of the subject were investigated:—

(1) Variation of combined carbon with temperature and time of heating, after quenching.
(2) Hardness to be anticipated in quenched specimens.
(3) Variation of microstructure with time and temperature of heating, in comparison with that of as-cast specimens.
(4) Hardenability of nodular irons.

The second section of the investigation covered determination of the effect of heat treatment on impact strength and tensile properties. No. 2 iron only was used.

From the results of the two series of tests, the various sections of which are individually reported in tables, graphs and photomicrographs, the author draws the following conclusions:—

'1. Heating below the A_1 line caused graphitization and the decomposition of pearlite to take place, while heating above the A_1 line resulted in the solution of graphite.

'2. Heating below the A_1 line and quenching in oil modified the hardness values so that they were roughly a function of the combined-carbon content, whereas

heating above the A_1 line and quenching in oil resulted in a martensitic structure having a hardness of R_c 58.

'3. Owing to the high affinity of magnesium for silicon, and since both elements were present in the nodular cast iron, small particles which were observed were believed to be magnesium silicide.

'4. The nodular cast iron had a high hardenability. To a great extent this was due to the manganese, silicon and nickel present. It is well to remember that various master alloys used to produce nodular cast iron may contain a high amount of elements such as copper, nickel, aluminium, etc. These elements are dissolved in the molten cast iron and may affect the hardenability as well as other properties.

'5. The impact values of quenched specimens were found to increase with tempering temperature, the increase becoming greater with the tempering temperature. A relatively high toughness was found for the annealed specimen.

'6. The tensile strength vs. hardness values of the quenched and tempered specimens were found to be similar to those of steel, but at high tensile strengths the ductility was quite low.'

Machinability Ratings of Nickel-containing Materials

See abstract on p. 6.

Abrasion-Resisting Nickel-Alloy Cast Irons

R. V. RILEY: 'Cast Iron for Crushing and Grinding Machinery.' *International Chemical Engineering*, 1950, vol. 31, Nov., pp. 500-2, 516.

Qualities required in abrasion-resistant castings are reviewed: hardness, toughness, wear-resistance, fatigue-resistance. This summary is followed by a consideration of the properties of the following cast materials, which have proved satisfactory for various types of abrasion-resisting service: white iron, high-duty low-alloy irons, martensitic irons, high-chromium irons and chromium-molybdenum irons. The importance of soundness, in all types of casting for abrasion-resisting service, is emphasized. The following summary is made of typical compositions and properties of the respective grades of cast iron employed in such applications.

A table lists some 60 applications of abrasion-resistant cast irons.

Table I
Abrasion-Resisting Irons

Composition	White Iron %	Low-Alloy Nickel-Chromium Iron %	Martensitic Iron %	High-Chromium Iron %	Chromium-Molybdenum Iron %
Carbon	3·0	2·8 -3·1	2·5	1·25-2·5	2·5 -2·7
Silicon	0·6 -1·0	1·5 -1·8	0·5 -0·8	1·5 -2·00	0·8 -1·4
Sulphur	0·05-0·15	0·08 max.	0·06 max.	0·05 max.	0·03-0·05
Phosphorus ..	0·20-0·50	0·30 max.	0·10 max.	0·05 max.	0·06-0·10
Manganese ..	0·20-0·60	1·2 -1·5	0·2 -0·6	1·0	0·8 -1·1
Nickel	—	2·5 -3·0	4·0 -4·5	—	—
Chromium ..	—	0·4 -0·6	1·3 -1·6	30·0 -33·0	18·0 -10·0
Molybdenum ..	—	—	—	—	4·0
Boron	—	—	—	—	0·05

Table II
Mechanical Properties of Abrasion-Resisting Irons

	White Iron	Low-Alloy Nickel-Chromium	Martensitic Iron	High-Chromium Iron	Chromium Molybdenum Iron
Transverse strength modulus of rupture (tons/sq. in.) ..	32	45	40	45	45
Tensile strength (tons/sq. in.)	15	22	20	30	—
Hardness (Brinell)	500	220	650	320	600

Ni-Hard Dredge Pumps

G. T. BATOY: 'Dredge Life Increased by Hard Alloy, Water Cushion, Double Casing.' *Mining Engineering*, 1950, vol. 187, Sept., pp. 942-3.

The article describes a pump developed for the following arduous service: pumping a mixture of slime-free sand, gravel and boulders, up to 6 in. in diameter, at the rate of 175 tons per hour, in one single-stage pump against a static head of 90 ft. and a total head of 140 ft., of which 20 ft. is on the suction side. The pump wearing parts were also required to have a minimum hardness of 550 Brinell, in order to give the necessary abrasion-resistance.

A pump of novel design has been successfully operating under these conditions for 1½ years in the gravel pit of John B. LaGarde, Inc., near Anniston, Ala., and it is believed that the design and materials used may be of interest in other applications in the mining industry, e.g., in pump transportation of coal-washer refuse or rock from open pits which is not very finely crushed.

An outstanding feature is that the pump is planned to take advantage of the high abrasion-resistance characteristic of Ni-Hard, which, due to low ductility of the material, has not been fully utilizable in large dredge pumps of conventional design.

In the new pump this difficulty has been obviated by utilizing the incompressibility of water. A one-piece Ni-Hard casing liner of volute design is mounted in, and surrounded by, an outer casing of ordinary cast iron. Within this casing, two Ni-Hard side liners are held in place in a smooth fit against the casing liner, by means of jack-screws through the outer side plate. These, together with a top jack-screw, position the assembly, and the Ni-Hard impeller operates within the enclosure so formed. The construction, and the relation of the shell liner to the outer casing, are such that there is a space of approximately 1 in. between the two, which is filled at all times with clear water, so that the shock and impact caused by heavy boulders, rams, water hammer or blow-backs, are cushioned by the confined body of water, and thus transmitted to the heavy cast-iron outer shell. It is this feature of the design that enables the extremely hard and non-ductile Ni-Hard to withstand the heavy shock loads. This putting of the gland water to double use also ensures that no damage can be done to the outer casing should the casing liner wear through. A second pump, identical with the one described, has been installed at the pit of the American Sand & Gravel Co., Hattiesburg, Mississippi.

CONSTRUCTIONAL STEELS

Steel Castings Handbook

STEEL FOUNDERS' SOC. OF AMERICA: 'Steel Castings Handbook.' 1950 edn.

Published by the Society, Cleveland, Ohio, 511 pp.; Price $4.

This Handbook, a revised and amplified edition of the 1941 publication, attempts to correlate, in one source, all information from the major literature, together with much additional, hitherto unpublished, data specifically made available by individuals and organizations both within and outside the steel-castings industry. It is pointed out that the war period witnessed many changes in the industry, with regard to production, technology, and application: the most recent developments have been embodied in the new edition. It is thus offered to the steel-making, steel-using, and engineering professions as an authoritative and practical reference book, 'for the use of all interested in the creation of improved industrial and mechanical structures of highest quality.'

The classification of the material presented is indicated by the following skeleton of contents:

History of the steel-casting industry; classes of steel castings; uses; design; manufacture; heat-treatment; mechanical properties (of carbon, low-alloy, heat-, and corrosion-resisting, and austenitic manganese-steel castings); physical properties (electrical, thermal, magnetic, etc.); engineering properties (behaviour under stress, hardness, wear-resistance, machinability, weldability); recommendations to purchasers of steel castings; specifications; definitions of foundry terms; chemical compositions of standard casting steels.

Machinability Ratings of Nickel-containing Materials

See abstract on p. 6.

Metals for the Motor Industry: B.S. Handbook

BRIT. STANDARDS INSTN.: 'British Standards for the Automobile Industry.' *B.S. Handbook No.* 8; 2nd (revised) edn., 1950; 513 pp.

Published by the Institution. Price 21/-.

In 1948 the British Standards Institution, in consultation with the Society of Motor Manufacturers and Traders, decided to incorporate the many standards of interest to the industry in one publication. This decision resulted in the issue of the first edition of the above Handbook; for scope see *Nickel Bulletin*, 1948, vol. 21, No. 12, p. 179.

Modifications in the second edition are based on experience gained in the use of the Handbook for the past eighteen months. Considerable re-arrangement of sections has been made, and a detailed alphabetical index has been added.

Sections of metallurgical interest in the Handbook include schedules of all steels generally used in the motor industry (pp. 272-354) and non-ferrous metals and alloys (pp. 356-93), and sections relating to methods of test employed for inspection and acceptance of metallic materials.

Nickel-containing Materials in Protection of Marine Structures

See abstract on p. 23.

Nickel-Alloy Steel Sucker Rods

'A Simplified Method for Design of Rod Pumping Installations.' *Petroleum Engineer*, 1950, vol. 22, Sept., pp. B.11, 16, 18, 36, 38, 42, 45-6, 48, 50-2.

A comprehensive report, from the Mechanical Engineering Group of the Atlantic Refining Company, presenting a discussion of factors which require consideration in design of sucker-rod pumping installations. Specific recommendations, charts, tables, etc., facilitate correct selection of the design and materials for service under specific conditions.

An important section of the paper relates to materials suitable for use in sucker rods operating in wells involving corrosive attack of varying severity. Specific recommendations are made with regard to the conditions in which rods of the following types will give satisfactory service: carbon, carbon-manganese, nickel-molybdenum, high-nickel, and nickel-chromium steel. Associated tables give additional information on endurance limits of rods of the respective materials, in various sizes.

Welding of Air-Hardening Nickel-Chromium-Molybdenum Steel

W. H. WOODING: 'Welding Air-Hardening Alloy Steels.' *Welding Jnl.*, 1950, vol. 29, Nov., Suppl. pp. 552-64.

The paper gives a closely detailed account of experiments carried out to develop a procedure satisfactory for the shielded metal-arc welding of nickel-chromium-molybdenum steel plates, 3¾ in. thick, of the following composition: carbon 0·42, manganese 0·38, silicon 0·15, nickel 3·60, chromium 2·30, vanadium 0·01, molybdenum 0·43, per cent. The material was required for fabricating a large rigid structure similar to one previously erected without undue difficulty in a nickel-chromium steel containing carbon 0·30, manganese 0·21, silicon 0·05, nickel 3·22, chromium 1·30, per cent.

'The results lead to the conclusion that the nickel-chromium-molybdenum steel is unsuitable for welded construction under conditions of high restraint and normal welding practice. The sluggishness of the material, preventing the formation of isothermal transformation products in the Ar′ region or region of austenite-ferrite transformation, intensifies an unfavourable condition in the heat-affected zones of welds, which are prone to cracking even under moderate restraint. The use of preheat has no appreciable effect in reducing the severity of base-metal quench, so that the cooling rate of the heat-affected zone would be sufficiently slow to permit the formation of any high-temperature transformation products. Preheat also had insufficient effect on the cooling rate established by heat radiation from the surfaces of the assembly to permit the occurrence of isothermal transformation products in the heat-affected zone prior to reaching the temperature of martensite formation. It appears that by regulation of preheat and interpass temperatures to within the range 450°-600°F. (232°-315°C.) (somewhat above the temperature of martensite transformation) and by maintaining the preheat temperature as a postheat temperature for a considerable period of time, 10-12 hours, after welding, sufficient austempering of the heat-affected zone should occur to permit completion of satisfactory welds under high levels of restraint. However, the use and maintenance of such high preheats over long periods of time is considered impracticable in so far as heavy construction is concerned.

'In view of the ineffectiveness of applicable preheat in obtaining satisfactory welds under high restraint, there appears but one alternative, and that is to keep the restraint from the weld during the time the heat-affected zone is in the condition conducive to cracking. This is accomplished by the cladding method. In this method the scarfs of the joint are clad with weld metal, using moderate preheat. The joint is then assembled, and by welding on the cladded surfaces, sufficient heat is developed in the heat-affected zone of the base metal, under the clad, to temper it into a condition where it will stand considerable strain without failure. Satisfactory welds may be deposited under high levels of restraint without using excessively high preheats.

'Underweld cracking occurring in air-hardening alloy steels when welded with low-hydrogen-type electrodes such as Type 310 (25-20) is associated with the isothermal characteristics of the base metal. Where restraint is not a factor, it appears that 8 per cent. bainite transformation is necessary to avoid cracking.

'As restraint is increased, the percentage of transformation product required to prevent cracking also appears to increase.'

HEAT- AND CORROSION-RESISTING ALLOYS

High-Temperature Nickel-containing Materials: Reference Data

F. H. CLARK: 'Metals at High Temperatures.' Published by Reinhold Publishing Corpn., New York, 1950; 372 pp. Price 7 dollars.

The author's avowed intention has been 'simply to compile the information recently made available on the properties of materials at elevated temperatures'. The book contains an assembly of the observations of many laboratories and others who have published, or contributed specially for this book, information on composition, properties and behaviour of a wide range of high-temperature materials now in use or under development.

In order to provide a theoretical background and to assist in the interpretation of the information presented, an introductory chapter of considerable length is devoted to the phenomenological aspects of plastic flow.

The arrangement of the main sections of the book is according to material, and in order to aid comparison of properties, classification within the individual chapters is, so far as is possible, arranged in a given

sequence, which is listed in the first chapter. The scope of the material presented is indicated below:—

(1) Introduction and Theoretical Aspects of Plasticity.
(2) Test Methods and Equipment for Testing at Elevated Temperatures.
(3-8) Composition and Elevated-Temperature Properties of
Plain-Carbon and Medium-Alloy Steels.
Chromium-Irons and Moderately Alloyed Austenitic Steels.
Highly Alloyed Austenitic Steels.
Cobalt-base Alloys.
Nickel-base Alloys.
Non-Commercial Alloys.
(9) Manufacturing Processes (Casting, Forming, Welding, Inspection, Design, Machining).
(10) Lower-Melting Alloys (Lead- and Aluminium-base Alloys).
(11) Scaling.

Each chapter is supported by an ample *bibliography* giving references to the original literature on which the text is based.

Constitution of Nickel-Iron, Nickel-Iron-Aluminium, and Nickel-Chromium-Iron Alloys

See abstract on p. 10.

Oxidation Mechanism of Nickel-Chromium Alloys

R. COURTEL: 'Electron Diffraction Study of the Oxidation Characteristics of a Metallic Alloy (80-20 Nickel-Chromium) Ground at Different Speeds, at Low Atmospheric Pressure.' *Rev. Métallurgie*, 1950, vol. 47, Sept., pp. 700-2; disc., p. 703.

In a previous paper (*ibid.*, 1949, vol. 46, pp. 24-6), the author reported the results of an investigation into the conditions of oxidation of iron when milled in vacuo or in a controlled atmosphere, the state of oxidation being followed by the electron-diffraction method. This method, which permits the average surface temperature during milling to be determined and changes in the crystalline phase to be followed, has also been employed in a study of surface changes occurring on cobalt ground in vacuo. The results of this work, already summarized in *Comptes Rendus*, 1949, vol. 229, p. 231, are reproduced here, together with four diffraction patterns.

A further application of the technique is now reported, to an 80-20 nickel-chromium alloy of the type already studied by a similar method by J. W. Hickman and E. A. Gulbransen (see *Trans. Amer. Inst. Min. Met. Eng.*, 1949, vol. 185, pp. 297-346; *Nickel Bulletin*, 1948, vol. 21, Nos. 8-9, pp. 125-6). Variation in the rate of oxidation with speed of grinding, i.e., with the surface temperature, was recorded, and it was found that below certain critical grinding speeds no oxidation is detectable in the diffraction diagrams. The feeble indications obtained at 23 m./sec. become very strong when the speed is raised to 28 m./sec., owing to the increased formation of Cr_2O_3, for which the critical speed of formation is about 25 m./sec. No increase in oxidation appears to occur beyond 28 m./sec., and no appreciable oxidation occurs below 15 m./sec. Just above this lower limiting speed, only NiO lines are found (as was also observed in the oxidation of pure nickel), and no Cr_2O_3 lines; NiO thus appears to have the lower threshold speed.

These results are discussed in the light of the observations reported by Chevenard and Waché (see *Rev. Métall.*, 1948, vol. 45, pp. 121-8; *Nickel Bulletin*, 1948, vol. 21, pp. 184-5) and by Gulbransen and Hickman (*loc. cit.*) on the selective oxidation of the elements of the alloy in question and the probable temperatures ruling at the different stages of oxidation. The main difference between the present author's work and that of the other authors referred to lies in the duration of the reaction, a fraction of a second with Courcel, and between 1 and 60 minutes with the others. The precise effect of this difference has still to be determined.

In the discussion, several speakers considered the author's assessment of the surface temperatures attained (400°-600°C.) too low.

Thermal Conductivity of Complex Nickel-Chromium-Iron Alloy

F. SCHMEISSNER and H. MEISSNER: 'Thermal Conductivity of Chroman B 2 Mo at Low Temperatures.' *Zeitsch. für angewandte Physik*, 1950, vol. 2, Oct., pp. 423-4.

Karweil and Schäfer, in 1939, reported exceptionally small thermal conductivity values, at sub-zero temperatures, for the alloy Contracid B7Mo (nickel 60, chromium 15, iron 16, manganese 2, molybdenum 7, per cent.). The alloy is not, however, produced as thin-walled tubing, and thus is not available for use in certain experimental apparatus for which its physical properties would render it peculiarly suitable.

The present paper reports investigation of the thermal conductivity of an alloy of somewhat similar composition which is obtainable as tubing. Chroman B2Mo is of the following type: nickel 61·4, chromium 18·5, iron 14·5, manganese 3, molybdenum 2, silicon 0·6, per cent.

Comparative data reported, for temperatures of 88°, 70° and 3·9°K. (−185°, −203°, and −269°C.), show that at 3·9°K. the thermal conductivity of the two materials is approximately the same. Electrical-resistance data are also presented, for temperatures of 286°, 90°, 74° and 4·2°K. (13°, −183°, −199° and −269°C.) and notes are added on the influence of pre-treatment of the material, and its resulting hardness, on thermal-conductivity values.

Cast Heat-Resisting Alloys: Factors Affecting Selection for Specific Applications

N. A. MATTHEWS: 'How to Select the 'Right' Cast Heat-Resistant Alloy.' *Steel*, 1950, vol. 127, Nov. 6, pp. 90-2, 94, 104, 106.

This article is an essentially practical survey of the properties of cast alloys of the types shown in Table I on p.17, and the uses of the respective grades for specific applications.

For these materials tabular data are presented on:—

Physical Constants (modulus of elasticity, density, melting point, specific heat, thermal conductivity, thermal expansion, specific electrical resistivity, magnetic permeability);

Table I

Standard Grades of Cast Heat-Resistant Alloys

ACI Type	C %	Mn % max.	Si % max.	P % max.	S % max.	Cr %	Ni %	Other Elements % max.*
HC	0·50 max.	1·00	2·00	0·04	0·04	26-30	4 max.	Mo 0·5
HD	0·50 max.	1·50	2·00	0·04	0·04	26-30	4-7	Mo 0·5
HE	0·20-0·50	2·00	2·00	0·04	0·04	26-30	8-11	Mo 0·5
HF	0·20-0·40	2·00	2·00	0·04	0·04	18-23	8-12	Mo 0·5
HH	0·20-0·50	2·00	2·00	0·04	0·04	24-28	11-14	Mo 0·5; N 0·2
HI	0·20-0·50	2·00	2·00	0·04	0·04	26-30	14-18	Mo 0·5
HK	0·20-0·60	2·00	3·00	0·04	0·04	24-28	18-22	Mo 0·5
HL	0·20-0·60	2·00	3·00	0·04	0·04	28-32	18-22	Mo 0·5
HT	0·35-0·75	2·00	2·50	0·04	0·04	13-17	33-37	Mo 0·5
HU	0·35-0·75	2·00	2·50	0·04	0·04	17-21	37-41	Mo 0·5
HW	0·35-0·75	2·00	2·50	0·04	0·04	10-14	58-62	Mo 0·5
HX	0·35-0·75	2·00	2·50	0·04	0·04	15-19	64-68	Mo 0·5

*Molybdenum not intentionally added.

Elevated-Temperature Strength Properties (100- and 1000-hour data and limiting creep stress for various temperatures up to 2100°F. (1150°C.) for which the respective alloys may suitably be considered);

Short-time Room-temperature Mechanical Properties and Hardness;

Ductility Values (per cent. elongation in 2 in.) calculated from stress-rupture tests of 50-200 hours' duration, at all or some of the following temperatures: 1400°, 1600°, 1800° and 2000°F. (760°, 870°, 980° and 1093°C.);

Maximum Operating Temperatures at which Surface Stability can be anticipated in air, oxidizing low- or high-sulphur, and low- and high-sulphur reducing atmospheres;

Carburizing Resistance (results of tests in carbo-nitriding atmospheres at 1650° (898°C.) for 1680 and 1200 hours, and at 1530°F. (830°C.) for 2500 hours). Much useful information is included in this table, the content of which is, in many cases, based on data obtained from commercial, as well as laboratory, tests.

A further useful feature is a condensed review of the function of the individual elements present in heat-resisting materials of the type under consideration; this is reproduced below, together with some of the main observations made in support of the tabular data referred to above.

Function of Individual Elements

Chromium Very important, and essentially only, property imparted by chromium is oxidation resistance. It exerts a minor beneficial effect upon hot strength.

Nickel This element is essential to a high degree of hot strength, since the austenitic phase is required. It also fortifies chromium in its rôle. It imparts carburization-resistance and resistance to thermal fatigue.

Carbon An austenite-forming element; exerts pronounced effect on hot strength. It is the main reason why cast alloys are generally superior in hot strength to wrought alloys.

Silicon Assists in oxidation- and carburization-resistance. In some grades it promotes a strengthening effect at elevated temperatures, up to a critical value, beyond which hot strength and ductility decline.

Nitrogen Of importance only in those grades where it may be employed advantageously to promote austenite. In straight-chromium grades it promotes grain refinement, resulting in improved ductility.

Manganese In minor quantities does not have any observed effect on properties.

Molybdenum Benefits oxidation-resistance to a limited extent and improves hot strength.

Niobium Has a potent beneficial effect on hot strength in some grades and a milder effect in others. Promotes resistance to cracking in thermal-fatigue service.

Interrelated effects among the several elements are important considerations in only the most critical applications.

Creep. A figure of 50 per cent. of the limiting creep stress is satisfactory for most non-cyclic high-temperature applications. If the part is loaded repeatedly for a short time during each cycle, the 100- or 1000-hour stress-rupture values provide additional data, permitting refinement in design.

Thermal cycling increases creep rates greatly in the 16-chromium 35-nickel alloy, and similar effects have been observed in the HH, HK and HU types of alloy. Effects typical at various service temperatures are quoted.

The ferritic alloy HC is relatively weak. It has exceptionally good ductility above 1200°F. (648°C.) but embrittles in service in the range 1200°-1650°F. (648°-898°C.). The alloys in which nickel predominates, HT, HU, HW and HX, have maximum strength up to approximately 1600°F. (870°C.); above this temperature the higher-chromium alloys such as HK become increasingly superior as the temperature increases.

Beneficial Effect of Nickel on Ductility. Hot ductility of the respective grades is not easy to compare exhaustively on the basis of data at present available; tests of long duration are required for full assessment of the relative position of the alloys with regard to retention of ductility. Data on stress-rupture (50-200 hours) indicate, however, that the higher-nickel alloys are superior in hot ductility.

Hot-Gas Corrosion-Resistance. The subject is discussed in relation to the three classes of atmosphere listed above, and the following comments are made: 'Sulphur is detrimental to alloys relatively low in chromium, especially when it occurs in a reducing atmosphere, which causes conversion of the contained nickel and iron to sulphides. Limited data available on sulphur levels corresponding to coke-oven gas suggest that the additional sulphur alters the picture adversely only in the case of those grades containing 35 per cent. or more of nickel, with correspondingly low chromium contents.'

Resistance to Liquid Baths. A common problem. Cyanide and lead baths are satisfactorily handled by the higher-nickel grades such as HK, HT, HU and HW. Special modifications of the 16 per cent. chromium 35 per cent. nickel types have been developed for neutral-salt service. Nickel must be avoided in alloy pots for magnesium-melting service: alloys with 18 to 24 per cent. chromium offer promise of effecting real economies. There is no known nickel-chromium-iron combination which will satisfactorily resist molten aluminium-base or copper-base alloys.

Resistance to Carburization. All heat-resistant alloys carburize, but the rate varies greatly and is influenced by carbon, silicon and nickel. Higher-nickel grades are standard for this type of service, because nickel retards the carburization rate. Even when carburized, the higher-nickel grades retain sufficient ductility to resist cracking from thermal cycling.

In connexion with susceptibility to carburizing, a warning is given as to the importance of adequate silicon and carbon contents.

Thermal Fatigue. Basically this is a stress problem, the stress arising primarily from thermal gradients. Failure is by surface checking, induced by repeated plastic deformation of the surface fibres of the material, which may be partially embrittled by carburization. Experimental study of this problem at the Alloy Casting Institute has established certain general trends, which are summarized. The 60-12 and 65-15 nickel-chromium-iron alloys are outstanding in this field and field tests show the 38-18 (HU) type also to be satisfactory.

Welding and Machining Qualities of Heat-Resisting Alloy Castings. The higher-nickel grades are easier to cast, and have satisfactory welding and machining qualities. Fluidity is favoured by the higher carbon and silicon contents common to these grades.

The straight-chromium alloy (HC) represents the other extreme, because of its high melting point and brittleness at room temperature, which exaggerate the straightening and welding problems.

All such alloys machine with difficulty in comparison with carbon steels, and, in general, relatively slow speeds and heavy feeds should be used.

Nickel-containing Alloys for Cyaniding and Carburizing Equipment

C. E. WENGER and G. C. McCORMICK: 'Selection of Alloys for Dry Cyaniding and Gas Carburizing Applications.' *Industrial Heating*, 1950, vol. 17, Oct., pp. 1751-4.

The article is written as a practical contribution to problems associated with the requirement for conservation of nickel in heat-treating equipment.

Reference is made to articles appearing in *Industrial Heating* of October, 1948, and October, 1949, which described a series of case histories illustrating the relation between design, soundness, and ultimate service performance of heat-resisting alloy castings. The present article, supplementing the information contained in those reviews, makes suggestions with regard to choice of material and design, on the combined basis of efficiency and economy, for the following types of apparatus: radiant tubes, trays, fixtures, miscellaneous parts. The vital relation between good foundry practice and suitable design is emphasized as a sine-quâ-non of economical utilization of the materials available.

Induction Melting of Stainless Steel: Selenium Degasification

R. J. WILCOX: 'Stainless by Induction Melting.' *Jnl. of Metals*, 1950, vol. 188, Nov., pp. 1311D-1311E.

This note, presented for discussion at the A.I.M.E. Electric Furnace Steel Conference, December, 1950, is based on experience and practice in the melting shops of Michigan Steel Casting Company, Detroit.

The conventional basic linings of the fired-position furnaces used consist of magnesia-alumina grain (Normagal), rammed in place dry, round an asbestos form, to provide a crucible having mean diameter of 16 in. and depth of 21 in. Sidewalls are 3-in. thick. For details of lining construction and burning-in

practice, reference is directed to the 1946 Proceedings of the Electric Furnace Steel Conference.

In melting nickel-chromium stainless steel some 80 per cent. of the charge is scrap of 18-8 and related grades of accurately known composition. The following procedure is given as typical of that used for production of Type 304 steel:—

'The nickel in the form of 9-in. square electrolytic cathodes usually is placed directly on the furnace bottom. This protects the bottom from dropping the balance of the charging materials into the furnace. The ferrochromium is added next, followed by the low-carbon steel or Armco ingot iron component of the charge, and finally by sufficient alloy scrap to fill the furnace. The power is immediately turned on to maximum input. There usually is more scrap in the charge than can be placed in the furnace at a single charging and it is necessary, as melting progresses, to continue the addition of alloy scrap until the entire charge, with the exception of the ferrosilicon and ferromanganese, has been added. No ore or slag-making materials are added.

'After the nickel, Armco iron, ferrochrome, and alloy scrap are melted, the bath is heated to nearly tapping temperature. At this stage, usually there has accumulated a considerable slag covering. The power is turned off and the slag removed as cleanly as possible. The power is returned to the heat, the ferrosilicon and ferromanganese are added, and special degasification additions are made. Tapping temperatures of these alloys are usually from 3000° to 3200°F. (1650° to 1760°C.).

'After the tapping temperature has been reached, a final degasifying addition of ferroselenium is made, in the amount of $\frac{1}{4}$-lb. of ferroselenium per ton. This addition is in the order of 0·0125 per cent. selenium, since ferroselenium contains an average of 50 per cent. selenium. This practice has been found to be a definite insurance against gas porosity of the reducing-gas type, frequently experienced from high hydrogen or nitrogen contents.

'Selenium degasification has replaced former methods of combating hydrogen and nitrogen porosity, such as oxidation with ore during melting or the use of inert gas injections prior to tap. It is the result of considerable experimental effort in which it was found that minor quantities of selenium are extremely effective.

'Extensive studies have been made to determine the effect of a minor selenium content on physical and mechanical properties, welding characteristics, and resistance to corrosion. No measurable effect exists on such properties with selenium up to approximately 0·10 per cent.'

The striking effect of selenium additions is demonstrated by illustrations of (1) a casting of 18-8 of high gas content, and (2) a casting poured from the same metal after treatment with 0·01 per cent. selenium.

Experience in induction melting of this steel, over several years' operation, indicates the following approximate percentage recoveries: carbon 100, chromium 99, nickel 100, manganese 90, silicon 94, molybdenum 95, niobium 92, selenium 89. Data on power consumption and costs are given in the note.

It has been found that development of the selenium-degasification treatment, combined with rigorous segregation of scrap to known compositions, has made possible the consistent production, by induction melting, of a dependable product from high-scrap charges.

Centrifugal Casting of Nickel-Chromium Steels in Permanent Moulds

W. F. WILSON: 'Centrifugal Casting in Permanent Molds.' *Product Engineering*, 1950, vol. 21, Nov., pp. 112-16.

The article deals specifically with the process used by Lebanon Steel Foundry for production of high-alloy heat- and corrosion-resisting steel castings. The method is a modification of 'true' centrifugal casting, in that it uses permanent, instead of refractory, moulds. In the modified method, the circular mould is rotated about its axis, either horizontal or vertical, while the molten metal is poured and the casting cools and solidifies. No centre core is used, since centrifugal force causes the liquid metal to assume the shape of the mould into which it is cast. Permanent moulds used in this process are made from steels specially selected for the purpose; die material depends on the shape of the casting being produced, the material being cast, and its melting temperature. Metal dies have the advantage, over refractories, of eliminating mould erosion, giving castings of finer grain size, and lowering production costs, due to longer mould life. It is also possible by this process to obtain enhanced properties in the castings, and to produce, in high-temperature materials, parts of complex structural shape which cannot be satisfactorily cast by static methods.

Metal conservation and reduction in machining time achieved by permanent-mould centrifugal casting are diagrammatically demonstrated, and two tables show the range of alloy steels (high-alloy, and carbon and low-alloy types) suitable for production of castings by the methods described. Typical alloy-steel rings, and the wide variety of sizes which can be produced, are illustrated. Centrifugal castings so made are finding increasing use in jet-engine parts and in other applications where the requirement is for sound, dense, strong castings which can be made on an economic basis.

Stainless Steels: Reference Data on Composition and Properties

E. W. COLBECK: 'Stainless Steels.' Proc. Manchester Assocn. Engineers, 1949-50.

A condensed but informative review of the high-chromium and austenitic nickel-chromium steels in general commercial use.

The first section of the paper contains a historical survey of development, from the initial discovery, by Brearley, in 1912, of the rust-resisting character of high-chromium steel, followed by work in Canada and the U.S.A.; the vitally important discovery, in Germany, of the austenitic nickel-chromium steels (for which a patent was granted in 1912), and research

on high-alloy nickel-chromium steels of various types, in France, Sweden, and England.

The main paper comprises a review of the composition, constitution, properties and uses of grades falling into the 'stainless' category. These are discussed in four main groups:—

(1) Straight chromium steels and chromium-irons containing 12-14 per cent. chromium.

(2) Higher-chromium stainless irons (15-18 per cent. chromium), and higher-chromium stainless steels containing up to 3 per cent. nickel.

(3) Higher-chromium steels (23-30 per cent. chromium) containing 0·1-0·3 per cent. carbon, and lower-carbon steels containing 23-28 per cent. chromium, modified by nitrogen additions.

(4) Austenitic stainless steels of the 18-8 and 12-12 per cent. types, and steels of the same basis composition, or of higher chromium and nickel contents, modified by additions of niobium, titanium, molybdenum and other elements.

The iron-chromium phase diagram is considered, as a background to a discussion of the unusual characteristics of steels containing chromium, and the influence of nickel additions is illustrated by tabular, graphical and photomicrographic data. Typical mechanical properties are listed for the respective groups of material under review, including sub-zero, as well as normal-temperature data. Corrosion-resisting qualities are discussed, in relatively general terms, exemplified by reference to some typical applications in which the respective grades of steel have proved their suitability. Attention is directed to the availability of free-cutting grades of several of the corrosion-resisting steels, and a final note is added on the properties of chromium-molybdenum steels containing 5 and 10 per cent. chromium, which, although falling somewhat outside the four main groups dealt with in the paper, are of closely related interest, due to their importance in the petroleum-refining industry.

Steel Castings Handbook

See abstract on p. 14.

S.A.E. (A.M.S.) Specifications

The following new or revised specifications are among those issued by the Society of Automotive Engineers on Oct. 1, 1950.

A.M.S. 5361 Steel Castings, Sand and Centrifugal, Corrosion and Heat Resistant; 18 Cr, 13 Ni, 2·5 Mo.
Range: Carbon 0·08 max., manganese 1·0-2·0, silicon 1·0 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 17·0-19·0, nickel 12·0-15·0, molybdenum 2·0-3·0, per cent.

A.M.S. 5521A Steel Sheet and Strip, Corrosion and Heat Resistant; 25 Cr, 20 Ni (S.A.E. 30310) (Deep Drawing and Spinning).
Range: Carbon 0·08 max., manganese 2·0 max., silicon 0·75 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 24·0-26·0, nickel 19·0-22·0, molybdenum 0·50 max., copper 0·50 max., per cent.

A.M.S. 5585 Alloy Tubing, Welded, Corrosion and Heat Resistant Iron Base; 20 Cr, 20 Ni, 20 Co, 3 Mo, 2 W, 1 (Nb+Ta).
Range: Carbon 0·08-0·16, manganese 1·0-2·0, silicon 1·0 max., phosphorus and sulphur each 0·030 max., chromium 20·0-22·50, nickel 19·0-21·0, cobalt 18·50-21·0, molybdenum 2·50-3·50, tungsten 2·0-3·0, niobium+tantalum 0·75-1·25, nitrogen 0·10-0·20, per cent., iron remainder.

A.M.S. 5640E Steel, Corrosion Resistant; 18 Cr, 9 Ni (S.A.E. 30303F) Free Machining.

	Type 1	*Type* 2
Carbon ..	0·15 max.	0·15 max.
Manganese ..	2·0 max.	2·0 max.
Silicon ..	1·0 max.	1·0 max.
Phosphorus ..	0·040 max.	0·12-0·17
Sulphur ..	0·18-0·35	0·040 max.
Chromium ..	17·0-19·0	17·0-19·0
Nickel ..	8·0-10·0	8·0-10·0
Molybdenum	0·75 max.	0·50 max.
Selenium ..	—	0·15-0·35
Copper ..	0·50 max.	0·50 max.

A.M.S. 5767A Alloy, Corrosion and Heat Resistant; Precipitation Treated Iron base; 20 Cr, 20 Ni, 20 Co, 3 Mo, 2 W, 1 (Nb+Ta).
Range: Carbon 0·08-0·16, manganese 1·0-2·0, silicon 1·0 max., phosphorus 0·040 max., sulphur 0·030 max., chromium 20·0-22·50, nickel 19·0-21·0, cobalt 18·50-21·0, molybdenum 2·50-3·50, tungsten 2·0-3·0, niobium+tantalum 0·75-1·25, nitrogen 0·10-0·20, per cent., iron remainder.

A.M.S. 5768A Alloy, Corrosion and Heat Resistant; Solution and Precipitation Treated.
Type and composition limits as for 5767A above.

Machinability Ratings of Nickel-containing Materials

See abstract on p. 6.

Nitric-Acid (Huey) Test for Use on Stainless Steels

M. H. BROWN: 'Boiling Nitric Acid Test for Corrosion-Resistant Steels.' *A.S.T.M. Bull.*, 1950, No. 169, Oct., pp. 20-1.

This short article is published in the series of 'Case Histories' reported to show the importance of using recognized standard test procedures in research work and in the development of new products. The purpose of the present contribution is to show why the test was developed, and how it has been used, and to point out its advantages and limitations.

It is emphasized that there has been a great deal of misunderstanding regarding the scope of the nitric-acid test. Although A.S.T.M. Recommended Practice A 262-44T indicates clearly that the test is recommended as a means of determining the *effectiveness of*

the heat treatment which has been applied to stainless steels, with particular reference to immunizing them from susceptibility to weld decay, the impression has been all too general that the results of the test could be regarded as a criterion of general corrosion-resistance to any media. This is definitely incorrect. So far as general corrosion-resistance is concerned, results are applicable only to the medium used, boiling 65 per cent. nitric acid. Neither are they applicable for predicting whether pitting or stress-corrosion cracking will occur in other media. *The primary purpose of the test in routine evaluation is to detect susceptibility to intergranular corrosion.* In this sense, and *only* in this sense, the results are applicable to any media which will intergranularly corrode susceptible material. However, the test does *not* indicate which other media are capable of attacking susceptible material in this manner, nor how quickly. Such information can be gained only through prolonged exposure in the particular media involved or by service experience.

A further limitation of the test must be recognized in connexion with the recently introduced extra-low-carbon 316 grade of stainless steel, where increased rates of corrosion in the boiling nitric-acid test resulting from exposure in the sensitizing temperature range may be due rather to sigma formation than to carbide precipitation. The test is, however, believed to be applicable to the E.L.C. 304 grade, where the complication of sigma formation does not occur.

Resistance of Nickel-containing Materials to Fluorine and Hydrogen Fluoride

W. R. MYERS and W. B. DELONG: 'Fluorine Corrosion: (A) High-Temperature Attack on Metals by Fluorine and Hydrogen Fluoride, and (B) Behaviour of Insulated Steel Parts in Fluorine Cells.' *U.S. Atomic Energy Commission M.D.D.C. 1465;* Declassification date, Nov. 13, 1947.

The necessity for generation and handling of fluorine on a large scale during World War II created serious problems for design and materials engineers. Little information was then available on materials of construction suitable for equipment handling fluorine, with the result that basic study of the subject was urgently required. This paper records some of the tests made to this end, in the laboratories of Du Pont Company.

The first section of the report deals with the resistance of metallic materials to corrosion by fluorine at elevated temperatures. Apparatus and mode of test are described and illustrated. The materials exposed were of the following types: nickel, Monel, Inconel, deoxidized copper, aluminium, magnesium, type 430 high-chromium steel, and types 347, 309-Nb and 310 austenitic nickel-chromium steels, Armco iron, and carbon steels of various carbon and silicon contents. Temperatures of exposure were varied over the range 200°-700°C. and the period was, in most cases, 4 hours.

The results (typical data are tabulated in the report) indicate that nickel and Monel show good resistance to fluorine at temperatures up to 500°C. None of the stainless steels tested is suitable for handling fluorine at temperatures above about 250°C. Aluminium and magnesium showed good resistance, and it is considered that the upper temperature limit for use of these materials will be imposed rather by their mechanical properties than by their resistance to corrosive attack. Carbon steels containing less than about 0·01 per cent. silicon are resistant up to approximately 400°C., but higher silicon materially increases the rate of corrosion, and it is believed that the silicon content of stainless steels may be also partially responsible for their poor resistance to corrosion. Above 400°C. corrosion rates for all the carbon steels are too high to make them useful for this type of service.

The second series of tests, made in anhydrous hydrofluoric acid at 500°, 550° and 600°C., showed that only nickel, Monel, Inconel and copper gave good resistance to attack.

In a third group of tests nickel and Monel were exposed to mixtures of hydrofluoric acid and steam, at temperatures of 550°, 600°, 650°, 700° and 750°C. Both materials showed reasonably good resistance up to the highest temperature of test.

In the investigation on fluorine cells it was found that anodic corrosion of steel in $KFH_2.HF$ at 90°C. increased rapidly with potential drops above approximately 5 volt.

Nickel-containing Materials in Chemical Plant: Cominco Trail Plant

E. A. G. COLLS: 'Corrosion Resistant Materials and Coatings in Trail Chemical Operations.' *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1950, vol. 187; *Mining Engineering*, Apr., 1950, pp. 491-4.

The paper opens with a condensed list of the materials which have to be handled at the Trail plant of the Consolidated Mining and Smelting Company of Canada:—

Gases: Sulphur dioxide, sulphur trioxide, carbon dioxide, carbon monoxide, oxygen, hydrogen fluoride, ammonia, hydrogen sulphide, and oxides of nitrogen.

Liquids: Solutions of ammonium sulphate, ammonium sulphite, ammonium nitrate, caustic soda and potash, sulphuric acid, nitric acid, hydrofluosilicic acid, hydrofluoric acid, phosphoric acid, aqua ammonia, and formic acid.

Solids: Gypsum (containing phosphoric acid), ammonium sulphate, ammonium nitrate, phosphate rock, caustic soda, potash, and phosphate fertilizers.

Some notes are then given on some of the major operations involved in the chemical processes used in fertilizer production, as typifying corrosion attack to which materials of construction may be liable.

Practical application of individual metallic and non-metallic materials is exemplified by reference to types employed in the sulphur-dioxide-recovery plant, and the hydrogen and ammonia, phosphate, sulphate and nitrate plants. As would be anticipated, the severe conditions obtaining in many of the operations

require the use of special materials, for example stainless steels of the silicon-containing type, Monel, high-silicon cast irons, etc.

The author notes that, in spite of the wide variety of stainless steels available to-day, only three are in large-scale use at Trail: the 316 type 18-8-Mo; 318, 18-8 containing niobium as well as molybdenum; 347, 18-8 stabilized with niobium. The potential usefulness of the E.L.C. stainless steels is being investigated, but none are at present in use at this plant. In general, experience at Trail confirms that 'chemical plants are inherently dependent upon the very best materials of construction for the particular purpose in hand, and without these materials the life of equipment and the maintenance costs become altogether uneconomic. There can be no question that in general, from the chemical plant operator's point of view, the best material available for any particular job at once becomes the cheapest material for that job, and this is strikingly borne out by actual maintenance and replacement costs.'

Nickel-containing Materials in Cathodic Protection Systems

A. L. KIMMEL: 'A Study of Some Metals for Use as Permanent Anodes in Water-Tank Cathodic Protection Systems.' *Corrosion*, 1950, vol. 6, Nov., pp. 353-8; disc., pp. 358-9.

In the design of cathodic-protection systems for water tanks, using an external source of direct current, correct selection of the materials for use as permanent anodes is of primary importance. This paper presents corrosion data on a number of materials which can be considered for this purpose. The studies were made in water of pH 6·3 and 6·8, the latter having the higher alkaline-earth content. The current density range for each material tested was $\frac{1}{4}$ to 4 amp./sq. ft.

The type of electrolytic cell employed is described and illustrated, and results for the respective series of experiments are reported at length. The anode materials examined were: aluminium (99·99 per cent.), aluminium alloy 3S, black iron (hot-rolled), commercial nickel, Monel, Inconel, stainless steel (Types 302 and 316). All these materials have been used as anodes or are potentially suitable for such application. For those which develop high water-to-anode resistance (e.g., aluminium), a rectifier with a wide voltage range should be specified, in order to maintain correct cathode current density.

Study of the anode-corrosion conditions observed indicates stainless steels of the 18-8 type as the most suitable material among those investigated. These steels are the most resistant to corrosion in oxidizing conditions, and the data presented indicate probability of good length of life. It is important that the surface finish of the steels should be as smooth as is economically possible.

On the basis of weight, aluminium is the least expensive, and is successfully used for this purpose, but aluminium anodes require more frequent replacement, and the requirement for a suitable rectifier unit must be considered as a factor in the all-over cost.

Iron anodes are least suitable, for various reasons, for use in water-tank protection systems.

Nickel, Inconel and Monel act alike in this application, and their corrosion-resistance, when used as anodes, decreases in the order indicated. It is important that these materials should be used in the annealed condition.

It is emphasized that the results presented are solely laboratory data, and that the conclusions drawn may require some modification in the light of field experience.

Nickel-Alloy Steel Sucker Rods

See abstract on p. 15.

Corrosion-Resistance of Iron-containing Cupro-Nickel

F. L. LAQUE and J. F. MASON: 'The Behaviour of Iron-Modified 70-30 Cupro-Nickel Alloy in Salt Water and in Some Petroleum-Industry Environments.' Paper presented to Corrosion Session, 15th Mid-Year Meeting, *Amer. Petroleum Inst., Division of Refining*, Cleveland, Ohio, May 2, 1950; 17 pp.

The object of this paper was to present in one place, for convenient reference, accumulated experience and laboratory test data illustrating the generally beneficial effects of small amounts of iron on the resistance of 70-30 cupro-nickel to attack by salt water. Additional information, relating to tests in petroleum refineries, indicate a still wider application for the improved alloys.

Following a review of the earlier literature, the authors summarize results obtained in tests made at the Kure Beach marine testing station, where a systematic investigation has been made of the effects of minor constituents on the behaviour of cupro-nickel alloys in sea water. The tests were, in many ways, closely parallel to those reported by Tracy and Hungerford (*Proc. Amer. Soc. Testing Materials*, 1945, vol. 45, pp. 591-613; *Nickel Bulletin*, 1945, vol. 18, No. 7, p. 108), but whereas Tracey's tests were in synthetic liquids, the Kure Beach tests were made in natural sea water and may therefore be considered as supplementary rather than repetitive.

The points of main interest from the various series of tests reported are briefly summarized below.

Immersion Tests in Flowing Sea Water

Although the main benefit of iron content in cupro-nickel alloys is realized under high-velocity conditions, tests were made to establish that the advantage gained in performance at high velocities would not involve sacrifice in resistance to pitting and corrosion in water at low velocity. Exposure of specimens under conditions known to accelerate pitting proved that in water at low and moderate rates of flow the iron-containing alloys also showed resistance to attack superior to that of iron-free alloys of parallel composition. A chart illustrates relation of iron content to corrosion-resistance for alloys tested at Kure Beach over the period 1939-1949.

Tests in Aspirator-Type Jet-Test Apparatus

The apparatus used in this series of tests was modelled on that developed by Bengough and May; it is described and illustrated. With it, determinations were made of the effect of air bubbles in aggravating corrosion attack. High-iron-content 70-30 cupro-nickel (0·47 or 0·51 per cent. iron) proved relatively insensitive, as compared with a similar alloy containing only 0·06 or 0·01 per cent. iron, which, at relatively low test velocity, was attacked more deeply when air bubbles were present. The high-iron alloy was significantly superior in resistance to impingement attack, whether air bubbles were present or not, and this superiority increased with severity of exposure, in terms of velocity.

Erosion Tests

Using apparatus designed at the U.S. Naval Experiment Station at Annapolis, tests were made to determine the relative resistance of iron-containing and iron-free cupro-nickels to conditions involving a combination of corrosion and erosion attack. The results reported confirmed the conclusions drawn from the Kure Beach tests, indicating the beneficial influence of iron content, and demonstrated that the higher-iron-content alloys are also highly resistant under conditions of raised temperature. This feature is of practical significance in connexion with their use in oil-refinery heat exchangers, where relatively high working temperatures may be encountered. It is believed that formation of the protective films upon which the erosion-resistance of the alloy depends is favoured by at least moderately high water temperatures.

Effects of Salinity of Water

Since tests at Annapolis were made in Severn water, and those at Kure Beach in full-strength relatively unpolluted sea water, comparison of the results at the two stations provided a means of assessing the influence of salinity. The data show that full-strength sea water is much more corrosive to low-iron than to high-iron cupro-nickel and that the latter alloy is highly resistant to both full-strength and brackish sea waters.

Tests in Rotating-Spindle Apparatus

Tests in this form of apparatus, details of which are given in the paper, confirmed the superiority of the high-iron content alloy in respect of its resistance in high-velocity conditions and showed that even after the protective film has been destroyed by erosion this alloy is attacked to a lesser extent than the alloy of lower iron content.

Metal-Potential Determinations

Determination of potentials of low- and high-iron-content alloys with reference to a saturated calomel half-cell, in turbulent sea water, showed potentials for the high-iron cupro-nickel about 10 millivolts lower (more noble) than those for the low-iron alloy. Under these conditions the low-iron material corroded about twice as fast as the higher-iron alloy.

Behaviour in Polluted Sea Water

Reports already published indicate that in polluted harbour waters, containing hydrogen sulphide resulting from decomposition of sewage and other organic wastes, the high-iron cupro-nickels show marked advantages. Further study of this aspect is in hand. Related tests, to demonstrate the influence of chlorination, showed that chlorine may be added to sea water in concentrations adequate for control of sliming and fouling, without introducing corrosion hazards which would seriously affect the iron-containing cupro-nickel alloys.

Tests in Petroleum Refinery Equipment.

The final section of the paper gives a tabular record of reports on behaviour of cupro-nickel alloys, in comparison with Admiralty brass, when exposed in various locations in petroleum refineries. The specimens were in the form of spool-corrosion test samples; the report shows conditions of exposure, penetration of corrosion (i.p.y.), pitting attack, with notes on other observations made. The results suggest that cupro-nickel has a satisfactory resistance to corrosion in handling of many petroleum products, and that it is especially suitable for equipment such as condensers or heat exchangers, where sea water, brackish water, or polluted sea water is used as coolant. Under severe impingement or velocity conditions a high-iron cupro-nickel is to be preferred. In this connexion, it is noted that the Bureau of Ships, U.S. Navy, has recently modified its tube and tube-sheet specification for main condensers operating at water velocities in excess of 7 ft. per sec., to require an iron content of 0·25-0·65 per cent. in the cupro-nickel.

The authors give a reminder that the cupro-nickel alloys are *not* resistant to sulphur compounds when the operating metal-wall temperature is in excess of 500°F. Apart from this limitation they may be expected to prove most useful in petroleum-refinery service, offering excellent inherent resistance to corrosion, freedom from dezincification, and low susceptibility to stress corrosion.

Nickel-containing Materials in Protection of Marine Structures

F. L. LAQUE: 'Protection of Steel in Off-Shore Structures.' Reprint from *Drilling*, 1950, June; 4 pp.

In steel supporting structures for off-shore drilling platforms and wharves the extent and severity of corrosive attack varies with the position of the structure relative to the water line. Tests made at the Kure Beach research station, reported in this paper, have shown that six zones can be differentiated: (A) below the mud line, where attack is not serious; (B) in the region of the mud line, where, although attack is not usually severe, certain conditions may arise to cause accelerated corrosion; (C) below low tide, where attack is relatively slight except in the area immediately below the low-tide level; (D) in the tidal zone, where corrosion is not likely, but if it occurs is difficult to eliminate; (E) in the splash zone of wave action above high tide, where corrosion will reach a maximum; and (F) in the atmosphere above the surfaces kept wet by waves, where corrosive attack is more severe than below low tide, but less than in the

splash zone. These six areas are illustrated by a sketch in the paper, which also shows the methods which may be adopted for protection of the susceptible areas.

In areas A, B and C principal reliance should be placed on cathodic protection, to preserve exposed surfaces: this may be supplemented by the use of conventional organic coatings, to reduce the area requiring cathodic protection, and to facilitate current distribution. Magnesium anodes have proved to be convenient sources of the protective currents; practical application of cathodic protection is illustrated in this paper, and the problems associated with the effects of fouling organisms are discussed.

Although, as indicated above, zone D is not usually an area of severe attack, it is one where complete prevention of corrosion is difficult, due to electrochemical effects, which are discussed by the author. In zone E (wave and splash area) the problems are more acute, and the difficulty of renewal of coatings under service conditions makes this method of protection unpractical. The author strongly recommends that the most satisfactory, and, ultimately, the most economical, means of protecting steel in the tidal and splash zones is to apply corrosion-resisting metal sheaths, of a material able to survive for the desired period of life of the main structure.

On the basis of the requirements of cost, availability, corrosion-resisting characteristics, fabricating quality and weldability, the alloys most suitable are Monel, and 70-30 cupro-nickel modified by the addition of 0·25-0·60 per cent. iron. To date, the majority of the work in this connexion has been done with Monel.

Minimum thickness of sheathing or cladding will be dictated by methods of fabrication and welding to be used. Where tubular sections are involved, it will be possible to construct them from Monel-clad steel. Nickel-clad steel is also being considered for this application, but since Monel is more resistant than nickel to localized attack in sea water, it has this inherent advantage over nickel. The choice between integrally clad steel and loose sheathing will be influenced by the lower cost of the sheathing vis-à-vis the compensating advantage of the more rigidly supported cladding. For protection of existing structures the choice is practically limited to sheathing, and sheet-metal sheathing is the only possible method of protection also for H-piles, treatment of which is discussed. Some typical illustrations of sheath and clad protection, using Monel and nickel, are given in the paper.

At the highest level under consideration, above the splash zone (F area) where surfaces can easily be re-coated, good use can be made of organic coatings, and consideration should also be given to the use of metallic coatings such as galvanizing, or sprayed aluminium or zinc. Any possible galvanic action between Monel sheathing or cladding, and zinc or aluminium applied in the zone above it, may be prevented by painting the Monel for a distance of 3-4 in. from the contact line. In this atmospheric-exposure area consideration should also be given to the use of low-alloy steels, such as those containing small amounts of nickel+chromium+copper. These steels have an inherent corrosion-resistance much superior to that of plain steel, and the performance of organic coatings on the low-alloy steels is better than on carbon steels of very low copper content.

A paper of related interest is the following:—

B. B. MORTON: 'Protection of Structures Exposed to Sea Water.' Paper presented at 5th Annual Petroleum Mechanical Engineering Conference, *Amer. Soc. Mechanical Engineers*, Sept., 1950.

This paper also draws attention to the different forms of attack to which the various zones of off-shore structures are exposed, illustrating this point by a graph showing the corrosion profile of steel piling exposed for 5 years at the Kure Beach station.

The different methods which may be used for protection in the respective zones are discussed (*vide supra*) and the practical interest of the subject is emphasized in relation to the many off-shore structures owned by oil companies, e.g., loading piers and other steel piers.

Nickel Alloys in the Paper Industry

'Construction Materials in the Paper Industry. Part II. Bleaching.' *Chemical Engineering*, 1950, vol. 57, Oct., pp. 217-18; Nov., pp. 255-6, 258-9, 261-4.

(Part I dealt with stock handling; see *Nickel Bulletin*, 1950, vol. 23, No. 11, p. 218.)

Part II contains information on the behaviour, in contact with bleach solutions, of high-silicon irons, cements, nickel and high-nickel alloys, Chlorimet, Durimet 20, tantalum, iron and steel, Worthite, coatings, lead and rubber.

Nickel and Nickel Alloys. Of the various bleaches used in the paper industry, those containing chlorine are the most highly corrosive. For many parts of the equipment tile or the use of rubber is preferred. Of the metallic materials available, a nickel-base alloy containing high percentages of chromium and molybdenum is practically the only one commercially available which gives adequate resistance to corrosion by wet chlorine. Monel, nickel, Inconel and Ni-Resist are unsuitable for this type of service, but Monel may be satisfactorily used for covers on the caustic extraction washers and on the hypochlorite thickeners. (Corrosion-test data are given in support of this recommendation.) Monel is *not* suitable for handling chlorine-bleached stock, but austenitic stainless steel of the 316 type has proved satisfactory.

Use of sodium peroxide as a bleaching agent has, in general, been restricted to bleaching of groundwood. Monel, nickel, Inconel and Ni-Resist are suitably resistant to attack by this type of alkaline agent, and in addition to giving long life, they have the advantage of preserving the quality of the bleached pulp by preventing colour contamination. Corrosion tests have also indicated the suitability of Monel for handling bleach stocks in which zinc hydrosulphite is present.

Chlorimet Alloys

Chlorimet 3 (nickel 60, molybdenum 18, chromium 18, iron 3 max., carbon 0·07 max., per cent.) shows excellent resistance to chlorine and chlorine-containing solutions at normal temperatures. It is resistant to moist chlorine gas, and to all hypochlorite bleach concentrations commonly encountered in pulp bleaching. Chlorimet 2 (nickel 62, molybdenum 32, iron 3 max., carbon 0·01 per cent.), is, however, severely attacked by chlorine in presence of moisture, and by unstable compounds. It is *not* recommended for use in bleaching operations, due to the oxidizing conditions involved.

Durimet 20 (nickel 29, chromium 20, molybdenum 2, copper 3·5, silicon 1, carbon 0·07 max., per cent., balance iron).

This material shows satisfactory resistance to many of the common bleach solutions used in the pulp and paper industry, but the concentration of chlorine tolerable is relatively restricted, and the greater suitability of the high-silicon-iron alloys (Duriron and Durichlor), and of the Chlorimet alloys, has resulted in but few applications being developed for Durimet.

Worthite (nickel 24, chromium 20, molybdenum 3, silicon 3·25, copper 1·75, per cent., balance iron).

This steel is stated to have attained a definite position for handling cold hypochlorite solutions. The upper limits of concentration for satisfactory service from Worthite pumps has been placed (as a result of long experience) at 3½ per cent. available chlorine for calcium hypochlorite and 3 per cent. available chlorine for sodium hypochlorite. These recommendations apply, in general, up to 90°F. (32°C.).

In multi-stage bleaching, where chlorine gas or chlorine water is used in the first stage, both hypochlorous acid and hydrochloric acid are usually present, resulting in solutions of low pH. For this stage Worthite is not recommended. For peroxide bleaching it has been found suitable for all known conditions.

Electrodeposition of Copper on Stainless Steel

See abstract on p. 8.

Stainless-Steel Powder Compacts: Infiltrated Compacts

G. B. STERN: 'A New Type of Stainless Powder.' *Proc. Sixth Ann. Mtg., Metal Powder Assocn.*, 1950, pp. 49-56; disc., pp. 57-8.

This report describes a further stage of the programme of development of stainless-steel powders referred to in the author's earlier paper; see *Materials and Methods*, 1950, vol. 32, July, pp. 52-4; *Nickel Bulletin*, 1950, vol. 23, No. 10, p. 196.

Characteristics and properties are given of the two grades of powder currently under investigation, No. 140 (14 per cent. chromium steel), and No. 188 (18-8 chromium-nickel steel). Both powders are of very low carbon content (0·02 and 0·04 per cent., respectively). Transverse-rupture test data and the mechanical properties of sintered compacts of the powders are presented. The results obtained to date are considered to justify the following conclusions:—

Equivalent pressing and sintering treatments develop higher densities and better mechanical properties in grade 140 than in grade 188 powder.

A commercially feasible production cycle consists in pressing at 35 tons per sq. in., followed by sintering for one hour at 1300°C. This will develop, in grade 140, a tensile strength of 30,250 p.s.i. (13·5 tons per sq. in.) and an elongation of 7·8 per cent.; the corresponding properties in the 188 grade after similar treatment are 19,875 p.s.i. (8·8 tons per sq. in.), with 6 per cent. elongation.

Re-pressing and re-sintering treatment appreciably improves the properties of both materials, e.g., tensile strength of 48,650 p.s.i. (21·7 tons per sq. in.), with elongation of 15·8 per cent. can be developed in the 140 powder compacts, and 31,800 p.s.i. (14·2 tons per sq. in.) tensile, with 11·8 per cent. elongation, in the 188 grade.

Corrosion tests on the sintered compacts of both powders showed good resistance to attack by salt spray, and by 30 per cent. nitric acid, cold or hot. Experiments in which compacts were made from grade 140 powder infiltrated with silver indicated properties of interest in connexion with bearing and contact applications. The same powder infiltrated with copper is considered to have characteristics which should prove useful for certain other special purposes.

PATENTS

Treatment of Lateritic Nickel Ores.

In a process involving the leaching of a reduced lateritic ore with an ammoniacal solution, the ore, before leaching, is treated in a reducing atmosphere, at a temperature above 650°C. (preferably 760°-870°C.), to reduce a substantial quantity of iron oxide, in addition to nickel compounds. It is then oxidized (preferably below 760°C.), and again reduced at a temperature lower than that employed in the first reduction, preferably at 315°-550°C.

INTERNATIONAL NICKEL CO. OF CANADA, LTD. *Brit. Pat.* 646,488.

Tri-Metal Bearing Materials

A material suitable for bearings is made by coating steel with an integrally bonded layer of nickel, and a relatively thick coating of molten aluminium or aluminium alloy cast against the coated surface. The material is rapidly quenched to bond the aluminium firmly to the nickel layer, with a minimum of reaction between the aluminium and the nickel. The material so produced may then be subjected to forming operations.

CLEVELAND GRAPHITE BRONZE CO. *Brit. Pat.* 646,506.

Nickel Anodes

An anode consisting of electrolytic nickel has an equi-axed grain structure, obtained by heating a cathode sheet having a columnar structure at 1250°-2500°F. (675°-1370°C.) for 20 minutes to 6 hours. It is claimed that anodes so prepared give improved plating from a variety of electrolytes, and dissolve uniformly.

HANSON-VAN WINKLE-MUNNING CO., assignee of B. C. CASE. *Brit. Pat.* 643,926.

Electrodeposition of Bright Nickel from Acid Baths

To a bath of the conventional type the following additions are made: a *N*-alkyl (1 to 6 C atoms) pyridinium pyrazole or a quinolinium pyrazole (0·001 to 0·02 g./L.) and a benzene sulphomide, benzene sulphonimide, benzene sulphonic acid or naphthalene sulphonic acid of 0·02 g./L. to saturation). A specific bath described consists of (g./L.) 200-300 $NiSO_4$. $6H_2O$, 125-45 $NiCl_26H_2O$, 40 H_3BO_3, 1-2 *o*-benzoyl sulphimide, 1·0 *p*-toluene sulphonamide 0·002-0·006 *N*-methyl acetate, 4-nitro-5 (-3′ -pyridinium) pyrazole chloride. The bath is operated at 110°-140°F. and a pH of 3-5.

H. BROWN, assignor to UDYLITE CORPN. U.S. Pat. 2,513,280.

Nickel-Copper Welding Electrodes

The electrodes claimed consist of a core wire of nickel-copper alloy and a flux coating of the following composition (parts by weight): 20-40 calcium carbonate, 5-35 calcium fluoride, 10-35 cryolite, up to 35 titanium dioxide, up to 8·5 manganese as ferro-manganese, up to 2·0 titanium as ferro-titanium, 2-5 bentonite, 5·5-8·0 niobium as ferro-niobium, and a binder containing 10-20 sodium silicate and 1·5-3·0 invert sugar. Such electrodes form crack-free weld deposits of high ductility, when used for d.c. arc-welding operations.

T. E. KIHLGREN, G. R. PEASE and P. E. LE GRAND, assignors to the International Nickel Co., Inc. *U.S. Pat.* 2,520,806.

Nickel-Alloy Magnetic Cores

Nickel containing up to 5 per cent. of a resistance-increasing element (vanadium, chromium, manganese, molybdenum, titanium, silicon or aluminium) is cold-worked to a reduction of at least 10 per cent., to produce tape of 6 mm. max. thickness. The tape is formed into a spiral core and the core is annealed at a temperature of 600°-650°C.

E. A. NESBITT and H. J. WILLIAMS, assignors to BELL TELEPHONE LABORATORIES, INC. *U.S. Pat.* 2,519,495.

Welding of Cast Iron

An electrode for welding cast iron consists of a core of nickel-iron alloy (nickel 40-75 per cent.) and a flux coating containing (parts by weight) 45-48 of slag-forming materials, carbon 10-30, titanium (in the form of an alloy) 0·25-2·5, iron powder 0-30, and a binder. The carbon content is such that the graphite content of the weld metal is 0·9-1·3 per cent.

MOND NICKEL CO., LTD. Brit. Pat. 645,958. (Pat. of addition to 621,936.)

Complex Wrought Nickel-Chromium-Iron High-Temperature Alloys

Wrought precipitation-hardened alloys showing high strength and ductility, and good creep properties at elevated temperatures, contain nickel 15-35, chromium 7-20, molybdenum or tungsten 2-5, titanium 1·3-1·9, aluminium up to 0·4, carbon less than 0·1, deoxidizers and scavengers 0·3-3·0, per cent., balance iron. The alloy is completely recrystallized and has a substantially uniform grain size, finer than No. 4 A.S.T.M. Such materials are suitable for rotors of jet engines.

H. SCOTT, R. B. GORDON and F. C. HULL, assignors to Westinghouse Electric Corpn. *U.S.Pat.* 2,519,406.

Complex Nickel-containing Cast High-Temperature Alloys

Alloys claimed to be characterized by high heat- and stress-resistance contain (by weight) cobalt 40-50, nickel 10-30, chromium 15-25, copper 5-6, molybdenum 4-5, iron 9·75, boron 0·25, per cent. Properties are quoted for a typical alloy of the following composition: cobalt 50, chromium 20, nickel 10, copper 5, molybdenum 5, boron 0·25, iron 9·75, per cent.

P. F. BLACKWOOD, assignor to FORD MOTOR CO. OF CANADA, LTD. *U.S. Pat.* 2,309,800.

Hard Solders for Joining High-Nickel Alloys

Alloys consisting essentially of nickel and chromium or nickel, chromium and iron are soldered by means of a solder consisting of a binary alloy containing palladium 92-95, aluminium 8-5, per cent., or a ternary alloy containing palladium 0·5-95·0, aluminium 0·1-8·0, per cent., remainder silver. Such alloys have a solidus temperature above 900°C. and a liquidus temperature below 1250°C. In the ternary alloy the silver may be wholly or partially replaced by gold, and some of the palladium may be replaced by platinum.

MOND NICKEL CO., LTD., E. C. RHODES and D. W. RHYS. *Brit. Pat.* 646,899.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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